Scientific Excellence • Resource Protection & Conservation • Benefits for Canadians
Excellence scientifique • Protection et conservation des ressources • Bénéfices aux Canadiens

Hydroacoustics Workshop Proceedings

Physical and Chemical Sciences Directorate
Department of Fisheries and Oceans
200 Kent Street
Ottawa, Ontario
K1A 0E6

July 1988

Canadian Technical Report of
Fisheries and Aquatic Sciences
No. 1641

Fisheries and Oceans
Pêches et Océans

Canada

89-04076/

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet, de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of

Fisheries and Aquatic Sciences 1641

July 1988

HYDROACOUSTICS WORKSHOP PROCEEDINGS

(Workshop hosted by the Bedford Institute of Oceanography,
Department of Fisheries and Oceans, Dartmouth, Nova Scotia
March 1-3, 1988)

Department of Fisheries and Oceans
Physical and Chemical Sciences Directorate
200 Kent Street, Ottawa, Ontario. K1A 0E6

©Minister of Supply and Services Canada 1988

Cat. No. Fs 97-6/1641E ISSN 0706-6570

DFO/4157

Correct citation for this publication:

Department of Fisheries and Oceans. 1988. Hydroacoustics Workshop Proceedings. Can. Tech. Rep. Fish. Aquat. Sci. 1641: 111p.

(aussi disponible en français sous le titre: Délibérations de l'atelier sur la détection hydroacoustique)

TABLE OF CONTENTS

Page

Abstract/Résumé v

Executive Summary vi

Résumé pour la direction.. iii

Welcome - J.-E. Haché.. 1

STATE OF THE ART REVIEWS

Sessional Chairperson: G.L. Holland

A Brief History of Underwater Acoustics and A Review of Basic Acoustics - S.B. MacPhee.................................. 2

New Directions in Acoustic Research - D. Farmer.................. 20

Progress in Fisheries Acoustics - R. Kieser...................... 27

Hydroacoustics in Biological Oceanography - Y. Simard............ 29

Acoustics in Physical Oceanography - D. Farmer................... 34

A Review of Acoustic Applications in the Canadian Hydrographic Service - G.R. Douglas............... 49

The Application of Hydroacoustic Techniques to the Study of Marine Mammals - S.E. Cosens...................... 52

Discussion on State of the Art Reviews - Rapporteurs - R.B.L. Stoddart and W.D. McKone................................ 56

ASPECTS OF SYSTEMS ENGINEERING

Sessional Chairperson: D. McKeown

Theoretical and Experimental Foundations in Fisheries Acoustics - R. Kieser................................ 58

Components of Sonar Systems - J.L. Galloway...................... 60

Signal Interpretation and the Use of ECOLOG in Fisheries Abundance Studies - P.R. Boudreau and L.M. Dickie.... 62

The Application of Image Analysis Techniques to the Interpretation of Acoustic Survey Data - N.A. Cochrane..... 63

Page

Geological Interpretation of Sidescan Sonar, Subbottom Profiler and Swath Sounding Data
D.R. Parrott and G.B.J. Fader.................................. 66

Interactive Visual Editing of Hydroacoustic Data from Fisheries Surveys - D.S. Miller and C.R. Stevens.......... 68

Discussion on Aspects of Signal Interpretation: Chairperson & Rapporteur - D. McKeown......................... 70

ASPECTS OF SYSTEMS ENGINEERING

Sessional Chairperson - J.L. Galloway

CSS 'FCG Smith' Hydrographic Acoustic Sweep Vessel - A.J. Kerr, A.L. Adams and R.G. Burke................. 74

Noise in Acoustic Systems - J.R. Parks........................ 83

Doppler Current Profilers - N.A. Cochrane..................... 89

Discussion on Aspects of Systems Engineering - Chairperson and Rapporteur - J.L. Galloway................................ 93

NEW CONCEPTS IN ACOUSTIC MEASUREMENT

Sessional Chairperson: D. Farmer

Fisheries Acoustics in the High Arctic: Under-Ice Applications - R.E. Crawford................................... 95

Two Acoustic Measurement Techniques for Recording Fish Movements During Migration - K.D. Cooke.................. 99

ACOUSTICS IN DFO - OPPORTUNITIES AND ISSUES, PANEL DISCUSSION

Sessional Chairperson - S.B. MacPhee

Panel Discussion on DFO Opportunities and Issues in Hydroacoustics - Rapporteurs - R.B.L. Stoddart and W.D. McKone.. 107

List of Participants... 111

Department of Fisheries and Oceans. 1988. Hydroacoustics Workshop
Proceedings. Can. Tech. Rep. Fish. Aquat. Sci. 1641: 111p.

Abstract

Overview papers were presented on the history and basic concepts of ocean acoustics, anticipated future directions of acoustic research, and on Departmental acoustic research initiatives in the areas of fisheries, biological and physical oceanography, hydrography and marine mammals. Subsequent sessions dealt with a suite of specific research projects in three general areas, namely: aspects of signal interpretation, aspects of systems engineering and new concepts in acoustic measurement. The final session consisted of a panel discussion, with subsequent involvement of all participants, on opportunities and issues in hydroacoustics that could be addressed by the Department of Fisheries and Oceans.

Ministère des Pêches et Océans. 1988. Délibrations de l'atelier sur la
detection hydroacoustique. Can. Tech. Rep. Fish. Aquat. Sci. 1641:
111p.

Résumé

On a ainsi présenté des communications générales traitant de l'histoire et des concepts à la base de l'étude acoustique des océans, des orientations prévues de la recherche acoustique et des travaux de recherche acoustique réalisés par le Ministère dans les domaines des pêches, de l'océanographie biologique et physique, de l'hydrographie et de l'étude des mammifères marins. Les rencontres qui ont suivi ont porté sur des projets de recherche réalisés dans trois grands domaines, à savoir: les aspects de l'interprétation du signal, la conception de systèmes et les nouveaux concepts touchant les mesures acoustiques. La dernière rencontre a pris la forme d'une discussion en comité à laquelle se sont joints par la suite tous les participants. On y a traité de possibilités et de points auxquels le ministère des Pêches et des Océans pourrait s'intéresser dans le domaine de l'hydroacoustique.

EXECUTIVE SUMMARY
Hydroacoustics Workshop
March 1-3, 1988

Acoustic measurements in the ocean are increasingly being utilized to measure oceanic conditions (air/sea interaction, currents, temperature), biological factors (plankton, fish, mammals) and hydrographic features (mapping the ocean floor). Hydroacoustic technologies are varied, complex and evolving at tremendous rates. As the third in a series of DFO Science workshops (climate and recruitment being the first two), the Bedford Institute of Oceanography hosted a gathering of Departmental scientists to discuss common interests, problems and opportunities in various hydroacoustic research and development initiatives.

The first day of the Workshop was slanted towards providing senior managers with an overview of the concepts, technologies and issues in the various hydroacoustic fields. Overview papers were presented on the history and basic concepts of ocean acoustics, anticipated future directions of acoustic research, and on Departmental acoustic research initiatives in the areas of fisheries, biological and physical oceanography, hydrography and marine mammals. Subsequent sessions dealt with a suite of specific research projects in three general areas, namely: aspects of signal interpretation, aspects of systems engineering and new concepts in acoustic measurement. The final session consisted of a panel discussion, with subsequent involvement of all participants, on opportunities and issues in hydroacoustics that could be addressed by the Department of Fisheries and Oceans.

A number of common issues were identified by participants throughout the course of the Workshop. These included:

(i) need to ensure a team approach to tackle acoustic R&D initiatives, including equipment, data collection capability and scientific and engineering expertise. The team approach can likely best succeed through the concept of "networking" to promote information exchange and through a willingness to exchange/lend acoustic capabilities amongst various responsibility centres.

(ii) the development of a centre(s) of excellence on acoustics could prove to be an invaluable mechanism to foster innovation and new concepts in Canada. It was recognized that such a centre could be university based with strong ties to federal government and industry initiatives and requirements.

(iii) more effort is required in a number of areas of acoustic R&D:

  (a) verification that acoustic measurements are true indicies of actual biological resources,
  (b) methods to convert acoustic data into biological data; e.g. signal interpretation,
  (c) development of good acoustic models,

(d) design of valid methodologies for fish surveys using acoustic techniques,

(e) techniques to deal with the processing and analyzing of the large data sets emanating from various acoustic sensors.

(iv) equipment calibration requires more attention and standardization if legitimate research results are to be obtained, and believed. An offshore calibration facility was contemplated in the 1970s and might be pursued interdepartmentaly again. An inventory of existing calibration capabilities might also be useful.

(v) need to ensure efficient use of acoustic instrumentation through their joint use by DFO researchers. Extension of frequency ranges to accommodate secondary users is also a possibility.

(vi) technological advances are proceeding at a faster rate than can be assimilated through procurement with available DFO resources. Survey work is often being undertaken with inadequate equipment.

(vii) university involvement in hydroacoustics research should be encouraged through the expanded resources now available to the DFO Science Subventions Program.

(viii) information exchange mechanisms on present and planned DFO acoustics research initiatives should be encouraged (i.e. "networking", additional workshops, program steering committees, etc.). In particular the DFO National Science Directors Committee should be briefed on the importance of and opportunities for hydroacoustic research in the Department.

RÉSUMÉ POUR LA DIRECTION
Atelier sur l'hydroacoustique
Du 1er au 3 mars 1988

Les mesures acoustiques en milieu océanique sont de plus en plus utilisées pour déterminer les conditions des océans (interaction air-mer, courants, température), certains facteurs biologiques (plancton, poissons, mammifères) et certaines caractéristiques hydrographiques (cartographie des fonds océaniques). Les techniques hydroacoustiques sont variées et complexes et évoluent à un rythme accéléré. Cet atelier est le troisième atelier scientifique parrainé par le MPO. Les deux premiers ont porté sur le climat et le recrutement. L'Institut océanographique de Bedford a été l'hôte de l'atelier. Plusieurs scientifiques du Ministère se sont ainsi réunis pour traiter de points, de problèmes et d'intérêts communs ayant trait à divers travaux de recherche et de développement dans le domaine de l'hydroacoustique.

La première journée de l'atelier a été orientée de façon à donner à la haute direction un aperçu des concepts, techniques et questions relevant des divers secteurs de l'hydroacoustique. On a ainsi présenté des communications générales traitant de l'histoire et des concepts à la base de l'étude acoustique des océans, des orientations prévues de la recherche acoustique et des travaux de recherche acoustique réalisés par le Ministère dans les domaines des pêches, de l'océanographie biologique et physique, de l'hydrographie et de l'étude des mammifères marins. Les rencontres qui ont suivi ont porté sur des projets de recherche réalisés dans trois grands domaines, à savoir: les aspects de l'interprétation du signal, la conception de systèmes et les nouveaux concepts touchant les mesures acoustiques. La dernière rencontre a pris la forme d'une discussion en comité à laquelle se sont joints par la suite tous les participants. On y a traité de possibilités et de points auxquels le ministère des Pêches et des Océans pourrait s'intéresser dans le domaine de l'hydroacoustique.

Plusieurs points d'intérêt commun ont été cernés par les participants au cours de l'atelier. Ce sont :

i) La nécessité de faire appel à une approche par équipes pour les travaux de R&D acoustiques, notamment ceux ayant trait à l'équipement, à la collecte de données et à l'expertise scientifique et technique. L'approche par équipes pourra sûrement s'avérer la plus efficace si l'on fait appel au concept du "réseau" pour favoriser l'échange d'information et si les intervenants sont désireux d'échanger et de partager leurs capacités techniques dans le domaine acoustique entre les divers centres de responsabilité.

ii) L'élaboration d'un ou de plusieurs centres d'excellence en acoustique pourrait s'avérer un mécanisme de très grande valeur pour favoriser les innovations et les nouveaux concepts au Canada. Les participants étaient d'avis qu'un centre de ce genre pourrait être situé dans une université ayant des connaissances approfondies des travaux et des exigences du gouvernement fédéral et de l'industrie.

iii) La nécessité d'accroître les travaux dans plusieurs secteurs de la R&D du domaine acoustique :

a) la vérification des mesures acoustiques en tant qu'indices représentatifs des ressources biologiques réelles;
b) les méthodes permettant de convertir les données acoustiques en données biologiques, p. ex. : l'interprétation du signal;
c) l'élaboration de bons modèles acoustiques;
d) la conception de méthodologies valables pour les relevés des poissons par techniques acoustiques;
e) la mise au point de techniques permettant de traiter et d'analyser les importants ensembles de données produites par les divers capteurs acoustiques.

iv) L'étalonnage de l'équipement devra faire l'objet de plus d'attention et être normalisé si l'on désire obtenir des résultats de recherche valables et crédibles. Une installation d'étalonnage au large avait été envisagée au cours des années 70 et plusieurs ministères pourraient se regrouper pour y donner suite. Un inventaire des capacités d'étalonnage actuelles pourrait aussi s'avérer utile.

v) La nécessité d'assurer l'efficacité de l'instrumentation acoustique de par son utilisation conjointe par les chercheurs du MPO. Il serait aussi possible d'accroître les gammes de fréquences et ainsi les mettre à la disposition des utilisateurs secondaires.

vi) Les ressources du MPO disponibles pour les acquisitions ne permettent pas de demeurer à jour, les progrès technologiques étant rapides et ne pouvant être assimilés. Il arrive souvent que des levés soient entreprises avec de l'équipement inadéquat.

vii) La participation des universités à la recherche hydroacoustique devrait être favorisée de part l'augmentation des ressources actuellement accordées au programme de subventions pour la recherche scientifique du MPO.

viii) Les mécanismes d'échange d'informations sur les travaux actuels et prévus du MPO dans le domaine de la recherche acoustique devraient être favorisés (par le travail en "réseau", d'autres ateliers, des comités d'orientation de programmes, etc.). Plus particulièrement, le Comité national des directeurs des Sciences du MPO devrait être informé de l'importance et des possibilités de la recherche hydroacoustique menée par le Ministère.

WELCOME TO PARTICIPANTS

J.-E. Haché

Good Morning, Ladies and Gentlemen:

On behalf of Scott Parsons, the Assistant Deputy Minister of the Science Sector, and indeed on my own behalf as Regional Director-General for Scotia-Fundy Region, it is a pleasure to welcome you here today to the National Workshop on Hydroacoustics, to welcome you to the Scotia-Fundy Region and to the Bedford Institute of Oceanography.

As many of you are aware, this is the third national workshop that is being held as part of the process of developing an ongoing national strategy for research. The first workshop on ocean climate was held at the Institute of Ocean Sciences in Patricia Bay, B.C., one year ago and the second one on recruitment was held last week in St. John's, Nfld. The first two workshops were most successful and after reviewing the program for the next three days there is every reason to believe that this one will also be a total success.

As a manager, while not totally conversant with the underwater acoustics field, I fully recognize the applications for underwater acoustic methods in hydrography, oceanography and in the biological sciences. I am also fully aware of the need to find new methods for estimating populations of the various species of fish in the most economical way possible. I am aware that while hydroacoustic techniques are already finding wide application for pelagic species the problem is much more complex for demersal species. I trust that during the next three days as hydrographers, oceanographers, engineers and fisheries scientists review this field together there will be much sharing of knowledge by all participants.

In closing, I would point out that the concept of sharing information in a national way to solve common problems is one that I fully espouse. No region should be expected to be by itself conversant in all areas of research. This common pooling of knowledge is probably one of the better examples of how we can do more with less in a departmental sense.

I wish you success in your workshop and hope that you find your stay here to be fruitful in every way.

A Brief History of Underwater Acoustics and A Review of Basic Concepts

S.B. MacPhee

Abstract

In this overview, historical information will be provided on the development of underwater acoustics from the early stages until the present time. The developments will be discussed in terms of acoustic applications for hydrography and the ocean sciences and include the use of acoustics to measure water depth, to detect undersea targets and to navigate. The use of acoustics for detecting fish and for quantifying fish in terms of size and abundance will also be included. In addition, underwater acoustic units and concepts will be discussed.

1. Introduction

What I plan to do today is to provide a brief history of the development of underwater acoustics from the early stages until the present time. I then wish to do a review of concepts and units to describe current applications of underwater acoustics in the disciplines of hydrography, physical oceanography and the biological sciences. Finally, I would like to give an impression of the future applications of acoustic techniques in these disciplines.

2. Development of Underwater Acoustics

2.1 A Brief History of Ocean Acoustics

Acoustics is the science that deals with the generation, propagation and reception of energy in the form of vibrational waves in a material medium. Underwater acoustics or sonar is the branch of acoustics dealing with vibrational waves underwater.

The recorded history of sound in the sea dates back to 1490 when Leonardi da Vinci wrote "If you cause your ship to stop and place the head of a long tube in the water and place the other extremity to your ear, you will hear ships at a great distance from you." This is the first example of a passive underwater listening device. Since that day, the understanding of sound in the sea has come a long way.

The early example quoted above, although deserving merit at the time, did not provide any indication of direction and was insensitive because of the great impedance mismatch between the acoustic properties of air and water. The concept of listening for underwater sounds by means of air filled tubes had nevertheless widespread use as late as World War I when by the addition of a second tube between the other ear and a point in the sea separated from the first point, the bearing of a source could be identified.

One of the first quantitative measurements in underwater sound occurred in 1827 when a Swiss physicist, Daniel Colladon, and a French mathematician, Charles Sturm, collaborated to measure the velocity of sound in Lake Geneva in Switzerland. By timing the interval between a flash of light and the striking of a bell underwater (Figure 2-1), they determined the velocity of sound to be 1435 m sec^{-1} at a temperature of 8° Celsius. Considering their primitive apparatus this degree of accuracy was remarkably high.

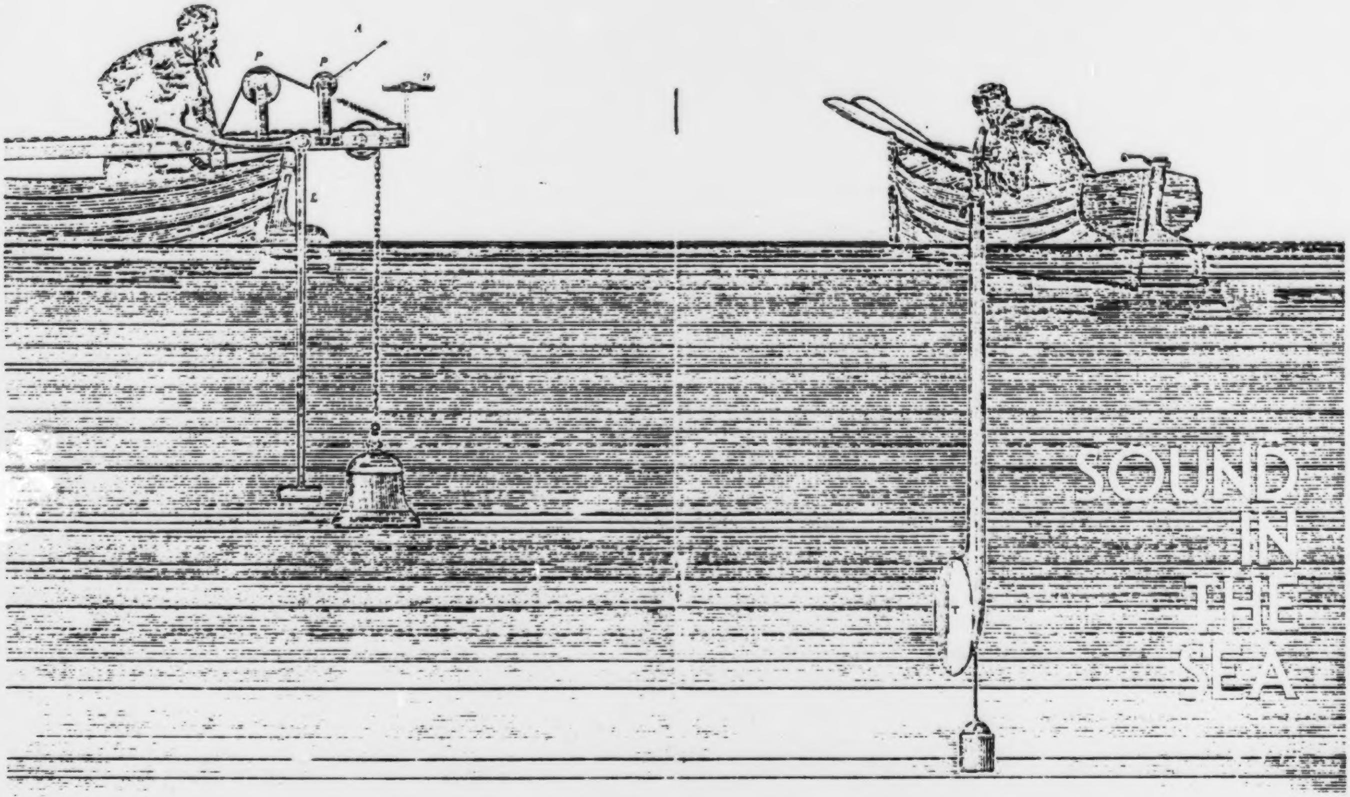


Figure 2-1. Colladon and Sturm's apparatus for determining the speed of sound in water. Two boats were stationed 13,487 m apart in Lake Geneva, Switzerland. A bell suspended from one of the boats was struck under water by means of a lever m, which at the same moment caused the candle l to ignite the powder p and set off a visible flash of light. An observer in the second boat with a listening tube measured the time that elapsed between the flash of the light and the sound of the bell. The mean of a number of such observations gave a value of 9.4s. The temperature of the water was 8°C. The experimental speed of sound in freshwater at 8°C was therefore 13,487/9.4 or 1435 m sec^{-1}. The results were reported in detail in 1827 and 1828. The empirical value given by (2.1) is 1438 m sec^{-1}. The near agreement to the fourth significant figure is fortuitous; only two significant figures are justified by the time measurement. (After Millikan et al., 1965 -- from Clay and Medwin)

One of the earliest uses of sound waves in the sea was the installation of submerged bells on lightships. The noise from these bells could be detected at a considerable distance through a simple microphone mounted in the hull of the ship. When the ship was outfitted with two detecting devices on opposite sides of the hull, it became possible to determine the approximate bearing of the lightship by transmitting the sounds separately to the right and left ears of an observer outfitted with stereo earphones. By timing the interval between the sound of the bell and the sound of a simultaneously sent blast of a foghorn, a ship could determine its distance from the lightship, the distance being about two-thirds of a mile per second time difference.

Although the results up until this time were worthwhile, a means of transferring acoustic energy efficiently to electrical energy and vice versa still had not been developed. However in 1880 Jacques and Pierre Curie discovered piezoelectricity, the property of some crystals when stressed to develop an electrical charge across certain pairs of crystal faces. A magnetostriction counterpart was soon discovered wherein a magnetic field produces a change in the shape of certain substances.

In 1912 the collision of the steamship TITANIC with an iceberg and the subsequent loss of hundreds of lives triggered man's use of sound for sensing in the sea. Within a month, L.R. Richardson, who had already filed for a British patent for echo ranging with airborne sound, filed another patent application (10 May 1912), this time for "detecting the presence of large objects under water by means of the echo of compressional waves having a wavelength in water of 30 cm or less ... directed in a beam ... by a projector..." (Hunt, 1954). R.A. Fessenden, who had been working on the same problem, filed for a U.S. patent on 29 January 1913 and succeeded in detecting an iceberg at a distance of 2 miles on 27 April 1914. The basic idea in all of this was that knowledge of the speed of sound in water, and the time of travel of the sound, permits the calculation of the distance to the reflector.

Meanwhile, in Europe, the urgent need for a submarine detector in World War I stimulated the imagination of a young Russian engineer, Constantin Chilowsky, who worked with the French physicist, P. Langevin, to develop an underwater source that transmitted sound across the Seine during the winter of 1915-1916. The British Allies, hearing of the French activities and successes, assigned Dr. Robert W. Boyle to organize a group to attack the same problem, and by summer 1916 the British had duplicated the French success. A major step forward was made when Langevin used as his sound source a sandwich of a plate of the piezoelectric material, quartz, between two plates of steel. The high intensities of this sound generator enabled transmission to a range of 8 km and produced the first detection of an echo from a submarine (Clay and Medwin). This really was the first recorded use of piezoelectric transducers for undersea sound transmission and reception.

At about the same time as Langevin was successful in France, Alexander Belum, a German scientist, is credited with the invention of the first echo sounder in that country.

These developments demonstrate quite clearly that while extensive use of sonar and echo sounding techniques was not in place until the mid-1930's the research was well underway by the end of World War I.

The years of peace following World War I saw a steady, though extremely slow, advance in applying underwater sound to practical needs. Depth sounding by ship was developed after World War I and by 1925 echo sounders or fathometers were available commercially. By 1935 several fairly adequate sonar systems had been developed and by 1938, with the imminence of World War II, quantity production of sonar sets started in the United States.

From a scientific standpoint, perhaps the most notable accomplishment of the years between World War I and World War II was the obtaining of an understanding of the vagaries of sound propagation in the sea. Early shipboard echo-ranging sets were mysteriously unreliable in performance. It is now known that this unreliability to obtain good echoes was largely because of the lack of knowledge concerning propagation in the medium and the changes encountered even over periods of less than six or eight hours.

2.2 Acoustics in Hydrography

Much of the early hydrography was carried out long before the advent of acoustic techniques. Depth soundings were obtained by lowering a hemp line or sounding line with a lead weight attached to the end. To illustrate an early reference from Saint Paul in the Acts of the Apostles 27: 27-29, it is written

> "... When the fourteenth night was come, as we were driven up and down in Adria, about midnight the shipmen deemed that they drew near some country; and sounded, and found it twenty fathoms: and when they had gone a little further, they sounded again, and found it fifteen fathoms. Then fearing lest they should have fallen upon rocks, they cast four anchors out of the stern, and wished for the day."

On reflecting on this passage, one wonders what would have happened if this situation had occurred in 1988 with bottom lock doppler sonar, acoustic navigation, global positioning and an electronic chart all fed from a satellite communicated ocean infrastructure data base with third party access -- of course. It is my feeling that the Apostle Paul would have become so confused, he would have prayed for a sounding line.

The sounding line did remain the instrument of the hydrographer for many years. While it was not too arduous a task for a leadsman in shallow water, it could take in excess of one day to make a single depth measurement in deep water. One of the earliest deep soundings was obtained by Captain James Ross in 1840 at a point halfway between Africa and South America. Using a 72-pound weight and a line of yarn attached to an enormous spool, a water depth of 2,425 fathoms was obtained (Idyll).

On the CHALLENGER expedition of 1872-76, stout hemp rope was flaked out on deck and allowed to run free over the side. It was consequently hauled back on board by hand over a steam capstan. From 1885 onwards the trend was towards using specialized winches and piano wire, greatly increasing the efficiency of the process. The Lucas and Kelvin-White sounding machines were among the more popular devices. It is interesting to note that by 1911, less than 6000 soundings of more than 1000 fathoms had been made. A modern swath surveying system, such as the SEABEAM system, is capable of making in excess of 6000 depth measurements in 1000 fathoms of water in less than five hours.

Prior to the advent of acoustic sounders two of the devices used to some extent were the harpoon sounder and the pressure tube sounder. The harpoon sounder (Figure 2-2) consisted of a seventy pound lead attached to a depth measuring device recording fathoms in accordance with the rotation of a small propellor. As the sounding lead plunged downward through the water, the propellor rotated driving a wheel through a worm gear. The number of rotations of the propellor was recorded on the wheel which was calibrated in fathoms of water passed through. After striking bottom, a clapper flipped down between the blades of the propellor stopping any further rotation while the sounder was being recovered and made ready for the next sounding.

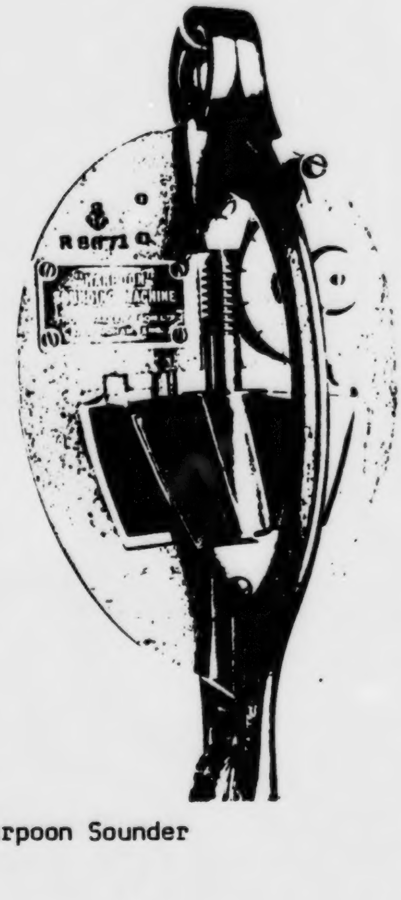


Figure 2-2. Harpoon Sounder

The Kelvin pressure tube (Figure 2-3) operated from a ship in the same fashion as the harpoon sounder registering depth as a function of water pressure.

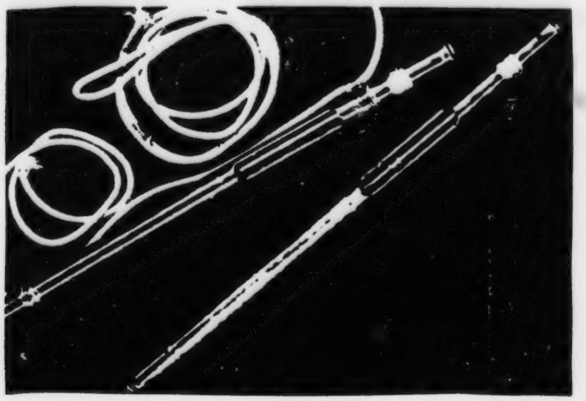


Figure 2-3. Pressure Tube Sounder

The first successful line of echo sounding was run across the Mediterranean in April 1922 in connection with a projected submarine cable and was reported in January 1923 by the Director of the French Hydrographic Service. In June 1922 the USS STEWART obtained a line of echo soundings across the Atlantic from the American coast to Gibralter and continued from Gibralter to Port Said. The American echo sounder was designed by Dr. J.C. Hayes of the U.S. Navy (Nature, 135, 1935).

The first echo sounder was not, however, fitted on a Canadian hydrographic vessel until 1929 when the installation was made on the CSS ACADIA. The machine did not employ an electroacoustic transducer but instead a compressor was used to operate a hammer against the bottom shell of the ship. The operator had to wear headphones, tune in the echoes and read off the depths as they flashed on a recording dial. With a rapidly changing bottom, the true echo was eventually lost and the "automatic" echo sounder frequently had to be reset by a leadline sounding obtained from the Lucas sounding machine.

The magnetostriction transducer was introduced on Canadian survey vessels in 1933 and besides having the advantage of operating in shallower waters it eliminated the wear and tear on the ship's hull from the continued operation of the pneumatic hammer.

The advances since 1935 have been for the most part in improving the transducer materials, in improving the electronics and in improving the signal processing. Areas that have been successfully pursued are in the nature of multibeam and sidescan sonar, multifrequency systems, replica correlation, signal enhancement and display systems. I will not pursue this matter further as this will be done by other speakers.

2.3 Acoustics in Physical Oceanography

Military demands prompted the early studies by physical oceanographers of the acoustic properties of water. There was a strong requirement, especially during the Second World War, to study the effect of thermal and salinity gradients on active and passive sonar systems. Gradually acoustics came into use for submarine and ship to ship communications via underwater telephones. Acoustic techniques now find application for doppler acoustic current meters, acoustic positioning, acoustic releases for subsea moorings and for many other applications in studies of water masses. The advent of acoustic tomography should in fact present a whole new field of research in acoustical oceanography.

2.4 Acoustics in Biological Research

Acoustics in a fisheries context may be separated into the categories of detecting fish and in the measurement of fish abundance. Fishing vessel captains and indeed scientists have been applying acoustic methods to the detection and study of fish populations since the 1930's. Research on the acoustic characteristics of fish and on the scattering cross sectional area of different fish species as a function of size and internal characteristics has been ongoing for many years. The implementation of the dual beam or nested transducer array system in the mid-1970's is probably one of the most significant developments as the combination of the narrow and broad beam transducers is designed to eliminate the uncertainties in determining the target strength of individual fish. The uncertainties are caused by the random distribution of the fish about the acoustic axis of the transducer.

An important problem currently being addressed is the identification of species. Two of the more significant developments in this area are ECOLOG, the dual beam system for determination of the population abundance of finfish and the SEASTAR system for measuring planktonic biomass.

3. Review of Units and Concepts

3.1 Review of Units

In underwater acoustics, except for in the USA, the SI system of units is used almost universally. These units are broken into base units and derived units. The base units are metres (m), kilograms (Kg), seconds (sec) and degrees Celcius (C). The derived units are units such as m/sec or m sec^{-1} for velocities and m^2 for area. Radians are normally used to measure plane angles, while steradians are used for solid angle measure — an isotropic radiator is directional over 4π steradians.

Pressure or acoustic intensity which until about ten years ago was measured in microbars ($1\ \mu bar = 1$ dyne $cm^{-2} = 0.1N\ m^{-2} = 0.1Pa$) is now normally measured in micropascals (μPa). One micropascal = 10^{-6} N m^{-2} or 10^{-5} dynes cm^{-2}. When quoting the acoustic source level of a projector, one would express the source level in Decibels (dB) with respect to one μPa at a range of one meter or dB // 1 μPa at a range of one metre. Some American texts and papers will still show dB // 1 μbar at a range of one yard. The decibel (dB) has long been in use for working with acoustic quantities. dB units provide a convenient way to handle large changes in quantities and in addition permit quantities to be multiplied merely by adding their dB equivalents in logarithmetic fashion.

The acoustic intensity of a sound source is therefore stated as the number of dB by which its intensity or energy flux density differs from the intensity of the reference sound wave or sound source. A sound source with an intensity of 220 dB would therefore imply an acoustic intensity of 220 dB // 1 µPa (dB with respect to 1 uPa at a reference distance of one metre). An associated parameter tying acoustic intensity to the electrical power input to a transducer is the transmitting response, a measure of the pressure on the acoustic axis from a unit current source in the projector. It is stated in dB // 1µPa/A referred to one metre from the source.

The reciprocal to the transmitting response is the receiving response. This is the open circuit voltage across the terminals of a transducer produced by a plane wave of unit acoustic pressure. It is measured in dB // 1V/µPa at one metre.

3.2 Factors that Determine the Propagation Velocity of Acoustic Waves in Water

One of the most important parameters to deal with is the velocity of pressure waves in water. The velocity is defined theoretically in terms of the density and elasticity by the formula

$$C = E/\rho$$

where E = modulus of elasticity in dynes cm^{-2}
ρ = density in gm cm^{-3}
C = velocity in cm sec^{-1}

In this formula, E is defined as the ratio of some given change in pressure to the accompanying fractional change in volume. Thus defined it is known as the VOLUME ELASTICITY or as the BULK MODULUS and may be written as

$$E = \frac{pW - pWo}{Vo - V/Vo}$$

where pWo = the initial volume of the total hydrostatic pressure of the water (dynes cm^{-2})
pW - pWo = the change in total hydrostatic pressure
Vo = initial volume (cm^3)
Vo-V = the change in volume

The DENSITY is simply defined as the mass/unit volume expressed in gm cm^{-3}. Since ρ and E cannot be measured directly, velocity is normally defined in practice in terms of three measurable quantities temperature (T), salinity (S) and depth Z (m). A simplified equation for the velocity of sound in water in terms of these parameters (Clay and Medwin) is

$$C = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.3 - 0.010T)(S-35) + 0.016Z$$

where C = velocity (m sec^{-1})
T = Temperature (°C)
S = Salinity (parts/thousand)
Z = Depth (m)

As indicated by the formula, velocity increases with temperature, salinity and depth. A typical deep sea velocity profile is shown in Figure 3-1.

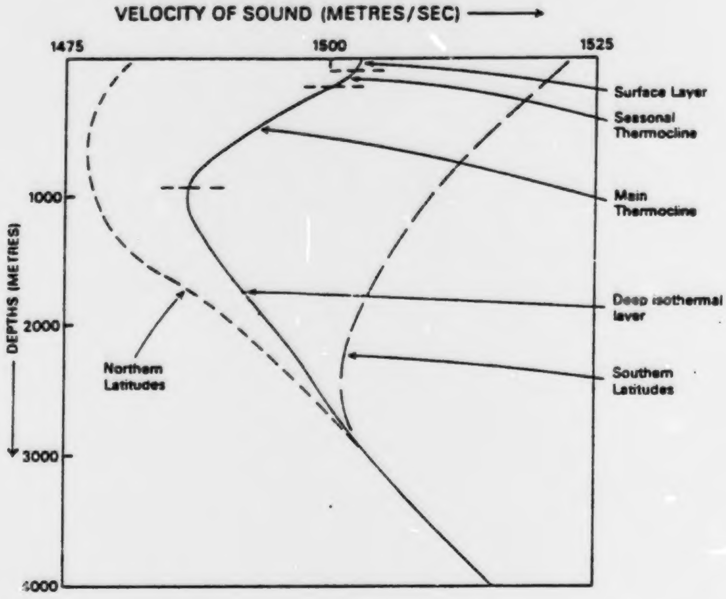


Figure 3-1. Deep Sea Velocity Profile. (Modified after Urick)

3.3 Factors that Determine the Losses of Acoustic Waves

The PROPAGATION LOSS is the signal loss (dB) that occurs between a point one metre from the acoustic centre of a source and some distant point in the sea.

The two main factors that contribute to the propagation loss of acoustic waves as they travel through a homogenous medium are the spreading loss and the attenuation loss. The spreading loss is independent of frequency and is merely the inverse square law loss as a result of the insonified area becoming larger. Spreading loss varies with range according to the log of the range and can be expressed as a certain number of dB/distance doubled. Spreading Loss = 20 log dist (m). This loss is illustrated in Figure 3-2.

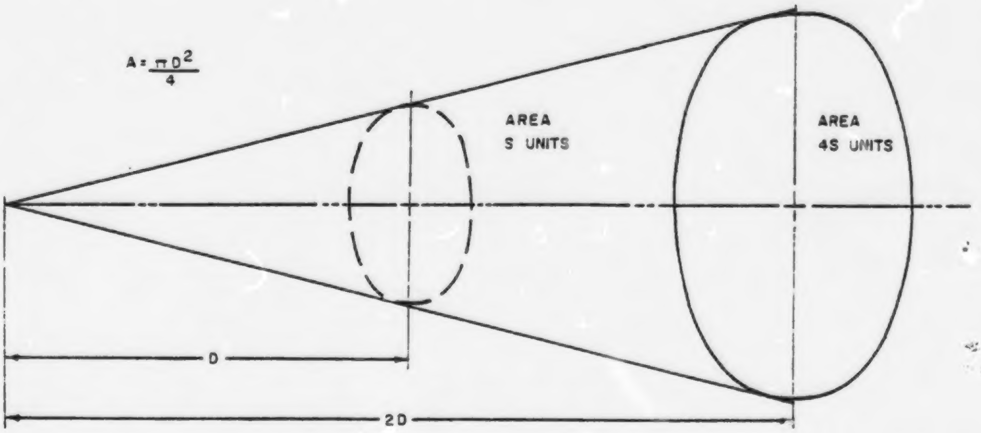


Figure 3-2. Illustration of Spreading Loss

Attenuation loss includes the effect of absorption, scattering and leakage out of sound channels. Attenuation loss varies with frequency, varies linearly with range, and is normally expressed as a certain number of dB/unit distance. Absorption, the major portion of the attenuation loss, involves a process of conversion of acoustic energy into heat and thereby represents a true loss of acoustic energy to the medium. This heat loss is caused by the repeated compression and expansion of the medium and the resultant friction between the water molecules. The attenuation loss caused by energy absorption plotted against frequency for both fresh and seawater is shown in Figure 3-3.

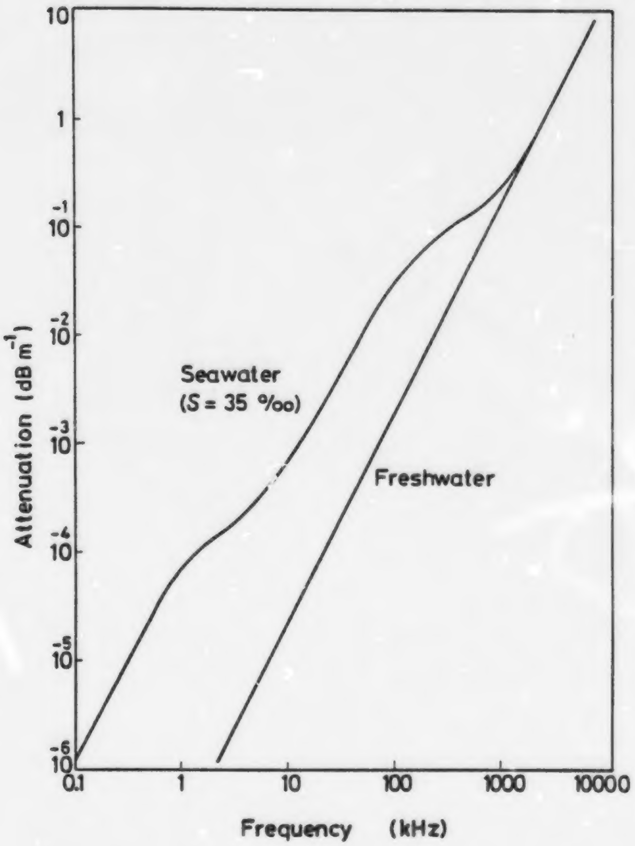


Figure 3-3. Attenuation of sound in seawater and fresh water as a function of frequency. (Modified from Milne, 1983 - after Williams, 1971)

For practical purposes, reasonable values of propagation losses may be obtained by summing the spreading loss and the absorption loss. When very accurate results are required one must in addition investigate scattering, reflection and other losses that may exist at the time of the experiment.

For any range the propagation loss may be obtained as the sum of the spreading loss and the attenuation loss caused by energy absorption by using the formula

Propagation Loss = $20 \, \mathrm{Log} \, r + \alpha r$

where r is the range in metres and α the attenuation coefficient in dB m^{-1}.

The total propagation loss in the medium as a function of frequency is illustrated in Figure 3-4.

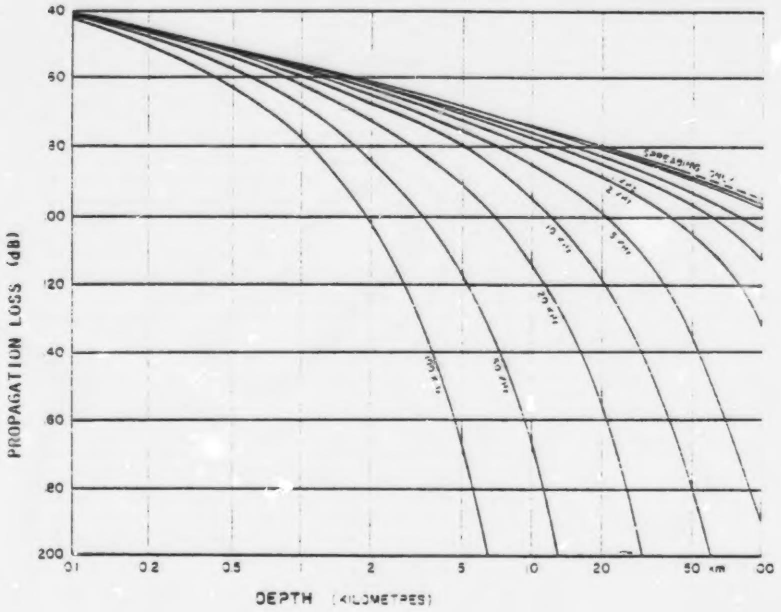


Figure 3-4. Propagation Loss Versus Range at Various Frequencies. (Modified after Horton)

In an active sonar or echo sounding system, the level of the returning echo from a given transmission (frequency and sound level specified) is dependent upon the range and also upon the BACKSCATTERING CROSS SECTION or TARGET STRENGTH of the target being insonified. The backscattering cross section is a measure of the ability of a body to scatter energy back to the receiver and the target strength is a dB measure of the backscatter.

The concept of total acoustical scattering cross section is used to describe the cross section of a body that is implied by the total power it scatters over all angles. It may be larger or smaller than the geometrical cross section, depending on the frequency. Scattering from spheres has been studied more thoroughly than scattering from any other shape and targets are normally calibrated in terms of the insonified area of a sphere. These calibrations can show the change in target strength or scattering cross-sectional area of marine bodies as a function of frequency, size, compressibility and material density. Scattering and target absorption is very well dealt with in Clay and Medwin. Typical target strengths for a number of targets are shown in Figure 3-5.

Target	Aspect	T.S. - dB
Submarine	Beam	25
	Bow-Stern	10
Surface Ship	Any	15-25 (highly uncertain)
Unsuited Swimmer	Any	-15
Fish	Dorsal (-4.4°)	21 Log l (cm) - 68.3

Figure 3-5. Various Sources.

Mitson shows separate regression equations for the target strengths of different species of fish as a function of and fish length. Target strength as a function of length and species is also extensively dealt with by Foote, Nakken and Olsen and by Dickie et al.

3.3.3 The Sonar Equation

Now that propagation losses in the medium and target strength have been considered, the other factors affecting sonar performance will be dealt with in terms of the sonar equation. The sonar equation ties together all of the different parameters that determine whether or not an echo is likely to be received from a given transmission.

The sonar equation can be expressed in terms of signal excess by using the formula

Signal Excess = $L_S - 2\,N_W + N_{TS} - L_N - N_{BW} + DI_R - N_D$
L_S = Level of Source = $170.8 + 10 \log P_A + DI_T$ in dB // $1\,\mu Pa$
$2N_W$ = 2 (one way transmission loss) = (attenuation + spreading) in dB
N_{TS} = Target Strength in dB
L_N = Level of Noise over 1 Hz bandwidth in dB // $1\,\mu Pa$
N_{BW} = Increased Noise due to wider bandwidth in dB
DI_R = Directivity index on receive in dB
N_D = S/N ratio required for processing in dB

In reviewing this expression it is noted that the parameters are determined by the equipment, the medium and the target.

In reviewing the terms, the source level (L_S) is a measure of the acoustic intensity referred to one metre from the centre of the source. It is determined by the transmitted electrical power, the transducer conversion efficiency and the directivity index of the transducer. The directivity index of a projector is a dB measure of the level of energy on the acoustic axis and the level that would be produced by an isotropic radiator, radiating the same total amount of acoustic power. The directivity index of a hydrophone is the dB measure of the amount by which a hydrophone array discriminates against noise by having a directional receiving response. In cases where the same transducer is used to transmit and receive, the directivity index is the same on transmit and receive. Expressed as a formula

$$DI = 10 \text{ Log } \frac{I_D}{I_{nonD}}$$

A pictorial representation of directivity index and a directivity index nomogram are shown in Figures 3-6 and 3-7.

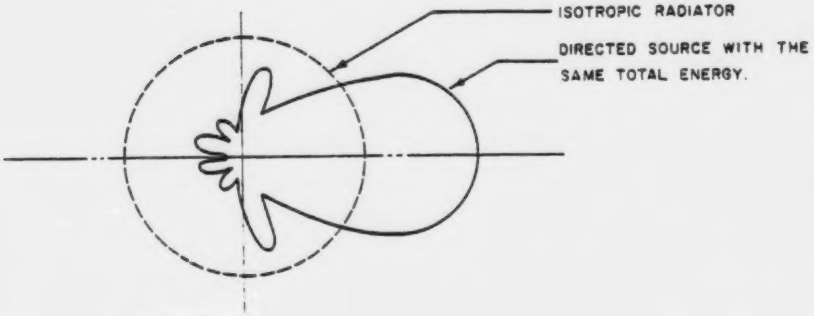

ISOTROPIC RADIATOR
DIRECTED SOURCE WITH THE SAME TOTAL ENERGY.

Figure 3-6. Pictorial Representation of Directivity Index

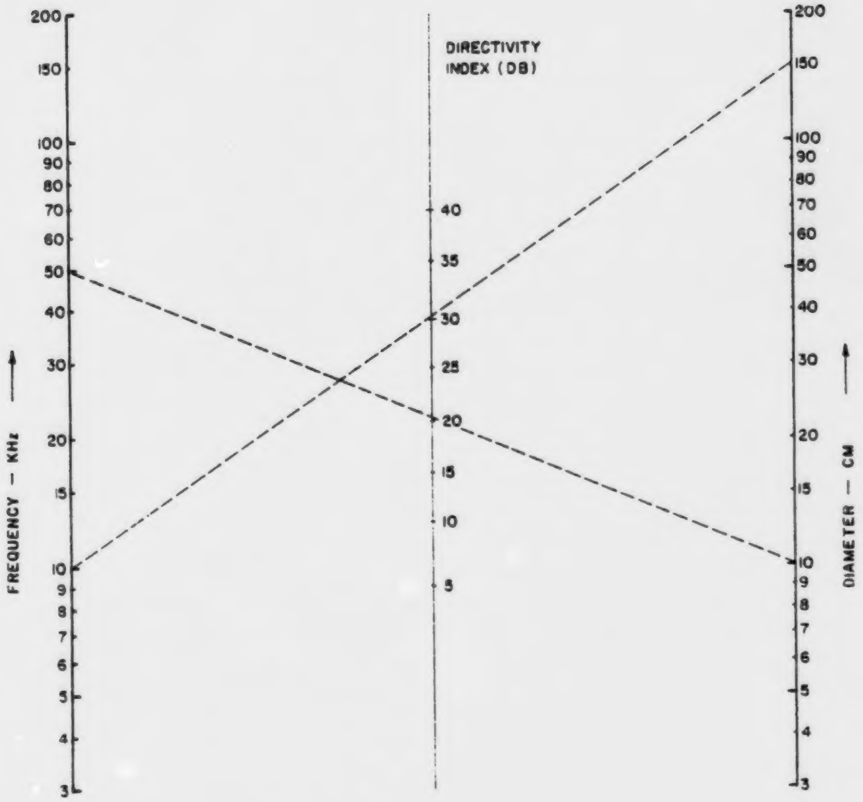


Figure 3-7. Directivity Index Nomogram

In the example given, reverberation masking was not considered. In an actual situation echo level, ambient noise level and reverberation masking level must be considered. The relationship is shown in Figure 3-8.

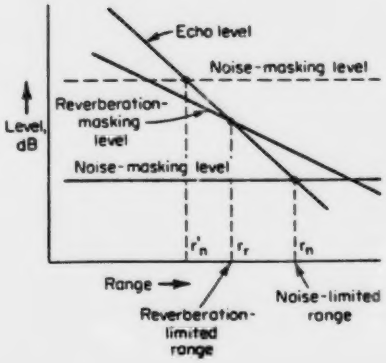

Echo level
Noise-masking level
Reverberation-masking level
Level, dB
Noise-masking level
r'n
rr
rn
Range
Reverberation-limited range
Noise-limited range

Figure 3-8. Echo, Noise and Reverberation as Functions of Range. (After Urick)

Transducer Beam Patterns

One important consideration for a transducer whether it be for echo-sounding, for acoustic navigation or for fish finding is the beam pattern or directional response. Simple sources and uniformly vibrating spherical shells radiate energy equally in all directions, but distributed arrays have unique directivity patterns. Pattern control is important because it is a method of concentrating a given quantity of energy more intensely, and also a method of reducing the amplitude of interference on a single transducer.

If one considers a continuous line source or a circular transducer, then the beamwidth to the 3 dB points is a function of the size of the transducer and the frequency. A circular transducer has a cone shaped beam while a rectangular transducer will have an approximately rectangular beam. For 12 KHz operation a transducer 0.5 metres athwartships by 2 metres fore and aft would have a fan shaped beam 12° wide by 3° in the fore and aft plane. Plots of beamwidth vs. transducer diameter at various frequencies are shown in Figure 3-9.

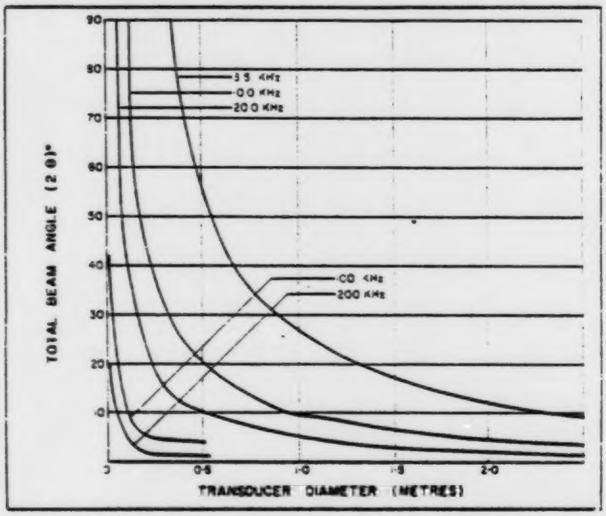


Figure 3-9. Beamwidth Versus Transducer Diameter

Other Definitions

Two other parameters that have not been considered but are still important are:

(i) Cavitation -- When the instantaneous value of the acoustic pressure exceeds the static pressure cavitation occurs and small voids or cavities are created in the area around the transducer. The cavitation threshold is raised by raising the frequency and by shortening the pulse length.

(ii) Specific acoustic impedance -- The pressure p is related to the velocity of the fluid particles u by

$$p = \rho C u$$

where ρ = fluid density
C = propagation velocity

The proportionality factor ρC is called the specific acoustic impedance

- For Water $\rho C = 1.5 \times 10^5$ gm cm^{-2} sec
- For air $\rho C = 42$ gm cm^{-2} sec

4. A Look to the Future

In the future it is felt that there will be a very strong emphasis on more complete sea floor coverage in inshore and offshore areas. In shallower waters, particularly in harbours and harbour approaches, in addition to the needs for surface navigation, it will become more and more important for total bottom coverage so that mines can be detected acoustically in times of aggression.

In fishing areas better bottom representation will be increasingly required in areas of extensive ground fishing. For offshore developments, total bottom representation including sea floor texture is essential in areas where exploratory and production wells will be drilled as well as for pipeline and submarine cable routes. In addition to the military requirements for more complete inshore hydrography, the military has for the past four years been most anxious to obtain sea floor physiography for coastal areas, particularly on the Pacific coast.

In the physical and chemical sciences areas, emphasis will be placed on acoustic doppler current meters and on acoustic techniques for the study of thermal and salinity structures in the ocean.

5. References

Although they are not all specifically identified in the text, the following publications were reviewed in the preparation of this paper.

Boudreau, P.R., and L.M. Dickie. Acoustic Measurement of mesoscale Distribution of Fish in Relation to Body Size. Proceedings of International Symposium on Fisheries Acoustics, June 22-26, 1987, Seattle, Washington, U.S.A.

Camp, Leon. 1970. Underwater Acoustics. John Wiley and Sons Inc., N.Y.

Caruthers, Gerald W. 1977. Fundamentals of Marine Acoustics. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands.

Clay, Clarence S. and Herman Medwin. 1977. Acoustical Oceanography. John Wiley and Sons Inc., N.Y..

Cox, Albert W. 1974. Sonar and Underwater Sound. D.C. Heath and Company, Lexington, Mass.

Dickie, L.M. and P.R. Boudreau. 1987. Comparison of Acoustic Reflections from Spherical Objects and Fish Using a Dual-Beam Echosounder. Canadian Journal of Fisheries and Aquatic Sciences, Issue 44(11): 1915-1921.

Dickie, L.M., R.G. Dowd and P.R. Boudreau. October 1984. Acoustic Estimates of Demersal Fish Using a Dual-Beam Transducer in Laboratory and Field. J. Acoust. Soc. Am., 76(4): 1175-1183.

Ehrenberg, J.E. 1974. Two Applications for a Dual-Beam Transducer in Hydroacoustic Fish Assessment Systems. Proceedings from IEEE '74 International Conference on Engineering in the Ocean Environment, Vol. 1: 152-155.

Fillmore, Stanley and R.W. Sandilands. 1983. The Chartmakers. N.C. Press Limited, Toronto.

Fischer, F.A. 1955. Fundamentals of Electroacoustics. Interscience Publishers Inc., N.Y.

Foote, Kenneth G. 1979. On Representing the Length Dependence of Acoustic Target Strengths of Fish. J. Fish. Res. Bd. Can., 36: 1490-1496.

Gray, N.G. 1983. Reminiscences of a Retired Hydrographer. Lighthouse Journal of the Canadian Hydrographic Association, Edition No. 28: 41-44.

Horton, J.W. 1957. Fundamentals of Sonar. U.S. Naval Institute, Annapolis.

Hunt, F.V. 1954. Electroacoustics. Harvard University Press, Cambridge.

Idyll, C.P. 1970. The Science of the Sea. Thomas Nelson & Sons Ltd., London.

MacPhee, S.B. 1979. Underwater Acoustics and Sonar and Echo Sounding Instrumentation. Canadian Hydrographic Service Technical Report.

Mitson, R.B. 1983. Fisheries Sonar. Fishing News Books Ltd., 1 Long Garden Walk, Farnham, Surrey, England.

Nakken, O. and K. OLSEN. 1977. Target Strength Measurements of Fish. Rapp. P.-v. Réun. Cons. Int. Explor. Mer, 17: 52-69, 1977.

Oceanus - Sound in the Sea. Spring 1977. Published by Woods Hole Oceanographic Institution, Vol. 20, No. 2.

Systems of Echo Sounding. 1935. Nature, 135: 896-900.

Urick, Robert J. Second edition 1975. Principles of Underwater Sound for Engineers. McGraw Hill, N.Y.

New Directions in Acoustic Research

David Farmer
IOS, Sidney, B.C.

Abstract

Acoustics is one of the most promising remote sensing techniques for the scientific study and resource exploration of the ocean. But in many ways its development remains quite primitive. In fisheries acoustics, for example, some effort is made to exploit frequency diversity and to correct for beam properties, but almost no use is made of phase information in the signal. Similarly, in hydrography, techniques such as spread spectrum processing, which have quite a long tradition of successful use in radar, have yet to be applied to sonar systems for bathymetric surveys. The availability of inexpensive high speed signal processing is starting to make it practicable to implement some of these ideas without a large investment, and many new developments can be expected in the future.

Advances are anticipated in the three primary categories of ocean acoustic studies: (1) Ambient Sound, covering the interpretation of naturally occurring sound in the ocean (both physical and biological), (2) Backscatter acoustics, which has a wide range of application in physical, biological and fisheries science, and (3) Forward scatter acoustics. Advances in each of these areas depend on a thorough understanding of the physics of sound generation and propagation, of the nature of the medium through which the sound travels and of the physical and biological properties of the scatterers. Examples will be used to illustrate the way in which the study of one particular aspect often leads to potential applications in others.

This workshop provides an opportunity for assessing our present capabilities in acoustics and planning future contributions. Acoustics is almost unique in our department as a scientific and technological endeavour that has application to all the major areas of DFO's interests. This is no coincidence. The ocean is essentially opaque to electromagnetic radiation. Acoustics is therefore the only effective form of radiation that we can use beneath the ocean surface. This presentation is concerned with the different types of acoustic remote sensing available to us and the scientific and technological advances presently being made, or which we can expect to see in the near future. Although I shall try to draw general conclusions, most of what I say is based on personal experience gained over the last few years through work carried out in the Graduate Studies program in Ocean Acoustics at IOS.

The ocean is characterised acoustically by its relative transparency over a wide range of frequencies, by the fact that it is a very quiet environment, and by its refractive properties that, under certain circumstances, can allow sound to travel great distances. There are three primary categories of acoustic remote sensing open to us:

Backscatter, in which artificially generated sound is reflected or scattered back to a hydrophone near to, or collocated with the projector. We think of backscatter as the primary remote sensing tool for bathymetric survey and fish stock assessment.

Forward Scatter, in which sound is transmitted at one point and detected somewhere else. As it travels, the sound is modulated by the ocean, and its physical and biological properties. This modulation might be treated as noise, for example in underwater positioning systems or underwater communication, or it might provide valuable information about the ocean itself.

Ambient Sound, the interpretation of natural sources of sound in the ocean. These sources may be associated with marine life, especially mammals, or with physical processes such as wave-breaking or the cracking of sea-ice.

Future developments in this field will be both scientific, in the sense of involving a deeper understanding of the physical basis of sound propagation and scattering in the ocean, and technological involving new instrument and analytical techniques. It is convenient to divide various areas of acoustic development into the three essential components of an acoustic system:

Sound Generation	Sound Propagation	Signal Detection and Processing
Natural Sources of Sound	Refraction	Signal Detection methods
Artificial Sources of Sound	Absorption	Directionality
Spatial Distribution/ Directionality	Scattering and Reflection	Amplitude/Phase
Parametric Sound Generation		Parametric Detection
Frequency Distribution		Signal Processing and Data Display

Consider first the potential for scientific developments:

1. Natural Sources of Sound: The ocean is filled with sound coming from many different sources. If we are to use these signals that nature provides, we must learn more about the way in which they are produced and how to interpret them. For example sound generated by breaking waves seems to have great variety, when measured in different places and at different times. If we can understand the mechanisms of sound generation and propagation we will be able to use this signal, detected from hydrophones suspended beneath drifting floats, or on the sea-floor, to learn much about the wave field on the surface and the coupling between atmosphere and ocean. Better theoretical models of the generation mechanism will help us to use the signals more effectively. Similarly, sea mammal calls, as discussed elsewhere in this Workshop, have the potential for being used to track and perhaps identify individuals. Perhaps we can use the rapidly developing methods of speech identification to help in this task.

2. Sound propagation over all but the shortest distances is dominated by refraction effects. Great advances have been made in recent years in the mathematical representation of these effects. Methods for studying 3-dimensional propagation are now being developed, but significant challenges remain, for example in the study of acoustic propagation through caustics and ocean fronts, and in shallow water. New developments can also be expected in the modelling of sound propagation near the ocean surface, which is an especially complex acoustic environment.

3. Sound is absorbed as it travels through the ocean. At higher acoustic frequencies the absorption, which is caused by certain molecular relaxation processes, depends uniquely on pressure, temperature, salinity and frequency. If the absorption can be measured at several frequencies the capability will exist for remote detection of temperature and salinity. At lower frequencies a different relaxation process depends sensitively on pH, which in turn depends on the dissolution of carbon dioxide. It has been suggested that long range propagation experiments could be used to monitor this climatologically important variable.

4. Much effort has recently been spent on the application of a concept referred to as acoustic tomography in which a criss-cross pattern of long range acoustic paths is used to detect mesoscale variability in the ocean. This must rank as the largest scale civilian application of acoustics in the ocean. It has not been an unqualified success, but the idea does show promise and new developments include applications in the Arctic, where sound propagation characteristics are quite different, and of ship based signal detection at a multiplicity of points. The latter development is important, since it will be practicable to sample the acoustic field more completely than has been possible with a purely moored array. (In this approach only the transmitters are moored, and these are switched on when the ship arrives.) Canada presently has no participation in this development.

5. Freely drifting floats are acoustically tracked over great distances in the SOFAR and RAFOS techniques developed by T. Rossby at the University of Rhode Island. The float position can then be used to track the movement of water masses at depth. This technique is also being considered for application in the Arctic. Significantly lower frequencies are required for long range propagation in the Arctic, due to scattering losses when the sound interacts with the ice. The efficient generation of sound at lower frequencies remains a significant technological problem. It appears that a significant Canadian contribution is in the making (see below, Sound Generation).

6. New developments can also be expected in the modelling and interpretation of sound scattering effects. Sound is scattered by temperature inhomogeneities, fish, bubbles, zooplankton, suspended sediment, pebbles and boulders on the sea-floor, the surface wave field, irregularities in the Arctic ice canopy .... The list is endless and scattering of one sort or another determines the nature of nearly all detected signals used in high frequency acoustics in the ocean.

Scattering depends on acoustic frequency and direction. Essential information for understanding the nature of the targets may also be contained in the temporal and spatial evolution of the scattered field.

The key to further developments here will be improved models of the scattering process. An everyday analogy may be helpful. If we look at a kangaroo, how do we know that it is a kangaroo? Aside from the context, we gain clues from its size, shape, its colour and the way it moves. In the acoustic analogue we might hope to identify a scatterer by its scattering strength, acoustic directionality, its acoustic properties as a function of frequency and its temporal characteristics (Doppler spectrum). This is true for acoustic scattering in the ocean. For example the size, shape, direction of motion and orbital velocities of surface waves can, in principle, be derived from the scattered signal. Can the same approach be used for species identification of fish? At present we do not exploit frequency dependence ('colour') except in a very limited way with dual frequency sonars, and to my knowledge the Doppler spectrum ('movement') is not used at all. Perhaps there is room here for significant development. But this will require much improved models of the acoustic properties of different fish, and of their behaviour, so as to develop unique acoustic signatures. Similar possibilities exist with respect to plankton studies. Laboratory observations will certainly be required for this purpose.

It is often useful to characterise the scattered signal by its statistical properties. A good scattering model can then be used to recover information about the distribution and nature of the scatterers. For example, statistical scattering models can be used to recover information about fine structure of the sea-floor that might be useful in certain bathymetric surveys. Statistical scattering techniques have definite potential in fish stock assessments.

Considering next the technological developments; the primary areas are sound generation, detection and signal processing.

1. New types of sound generation techniques include, among others, controlled broad-band sources, optical sound generation on the ocean surface using high powered lasers, and parametric sources. The need for sources that can transmit a wide range of frequencies (other than uncontrolled sources such as explosions) has always been a hurdle in ocean acoustics; new techniques are yielding much broader band devices. A potentially significant development is the plasma jet acoustic source currently under development at the University of Victoria. Parametric techniques, in which sound of two different frequencies is mixed non-linearly in the water to yield a third frequency, are being rapidly developed. Important applications include very narrow beam depth sounding, which may be of interest for deep water bathymetric surveys.

   As broad band sources become more readily available, there will be increasing motivation to make the transmitters 'smart', by transmitting signals encoded over a wide frequency range. Transmitters can also be made directionally smart with phased arrays, and significant developments can be expected with the use of acoustic lenses.

2. New developments in signal detection include the design of hydrophones based on principles of optical interferometry and having extraordinary sensitivity. New plastic based hydrophones can be 'printed' in any desired pattern much like printed electronic circuit boards, and should permit great flexibility in design. Parametric reception is a powerful technique for achieving high directionality with low frequency signals. Directionality can also of course be controlled with phased arrays of hydrophones and these techniques are becoming increasingly applicable at higher frequencies.

3. Signal Processing is the treatment of data following detection. Major advances include the development of very high speed digital signal processing (DSP) chips. The advance in processing speed can be illustrated by example. Four years ago, data from our acoustic scintillation system was processed on a mainframe computer, the IOS Univac; it took 1 hour of cpu time to process 10 minutes of data. With the advent of high speed correlator chips we built a special purpose computer to carry out the calculations in real time - 10 minutes of computing for 10 minutes of data. But the computer was quite large and consumed a lot of power. We are now building the same processing power into our system with a single DSP chip, small enough to fit in a pint-sized pressure housing alongside each transducer, and drawing minimal power. This kind of processing power opens up many possibilities in ocean acoustics. High resolution arrays of hydrophone elements will nevertheless pose still greater computational challenges requiring massive parallel processing capability. It may be that the new optical processing technologies will be a good match for these demanding requirements.

It is useful to see our present acoustic applications in terms of a hierarchy of progressively more sophisticated signal processing approaches. At the lowest level, for backscatter sonar, we have the simple detection of signal intensity. This is the technique normally used for bathymetric survey and (single beam, single frequency) fish stock assessment, although in the latter case echo-integration or related processing may be carried out. At the next level, frequency diversity is employed. Some fisheries sonars, for example, are dual frequency. Still more sophisticated is the use of controlled directionality; this is employed with split-beam or dual-beam echo-sounders, and in a more elaborate way, with the Sea Beam and related systems. Spread spectrum processing involves coding the transmitted signal in frequency space, and correspondingly decoding the received signal so as to achieve processing gain. So far, this approach does not appear to have been used for echo-sounding. The full spectral properties are used in Doppler and related devices for measuring flow speed profiles. The potential of the Doppler spectrum has yet to be used in fisheries applications. Information contained in frequency, direction and time can be combined in techniques such as synthetic aperture sonar, but these apparently remain in the development stage, as do various related acoustic imaging techniques. Parametric transmission is now used by the US Navy for depth measurement, but to my knowledge, is not yet widely employed in the civilian hydrographic service. This is not intended to be a complete list, but may give some idea of the potential for future developments.

The evolution of new ideas and technological skills often leads to new applications beyond the original area of interest. This can be illustrated with some examples taken from experience in the IOS Ocean Acoustics program:

1. Our studies of acoustic scintillation were originally aimed at learning how to measure flow speeds in tidal channels, by detecting the drift of temperature inhomogeneities through the acoustic path. This idea was successful and is now being adapted for commercial application. It did not take us long to realize that the signals we were detecting could also be used to study the structure of turbulence that caused the perturbation in the first place. We also discovered a way to measure direction with great accuracy, in effect combining the benefits of the ultra-short baseline method with the benefits of a long baseline, a technique that is now being developed for application to positioning systems. In order to gain enhanced signal processing we used spread spectrum techniques. We had heard about echo-sounder limitations on survey launches and this seemed a possible solution. The technique is now being developed for this purpose.

   What further side benefits might we expect from our scintillation studies? We would like to see the forward scatter concept applied to scattering by fish. This would have application to fish tracking and counting in channels and rivers. The application of this idea would require development of a good scattering model of the fish.

2. A second example comes from our studies of volume back scatter. My early interest in this was in flow visualization. We subsequently added Doppler, actually the measurement of the rate of phase change in the signal, in order to recover velocity profiles. In a subsequent study we became interested in the absolute orientation of the acoustic vector in space and time, rather than just its rate of change. As a result of a quite detailed statistical analysis, we developed the concept of a volume mirror, in which phase coherent scatter is achieved even though the targets are randomly positioned in the water column. The convergence of random phase towards a stable value with successive coherent processing of signals, can be related to the target density. This gives, in principle, a technique that could be applied to measurement of the number density of biological targets, with application to fisheries research.

3. The third example is from our ambient sound studies. These began with a test of the relationship between sound level and wind speed, motivated by the oceanographic interest in remote wind speed measurement. Our work led to the recognition that bubble clouds, injected by the breaking waves mask the higher acoustic frequencies; this masking can thus be used to infer the bubble cloud density and hence yields a measure of the extent of wave-breaking. Thus the ambient sound turns out to be a probe of more than just wind speed, and can be used to study several aspects of air-sea interaction. Rainfall has its own distinctive signature and can be detected acoustically. Detailed analysis of the sound generated by individual waves has yielded a still richer signal, which we are only just learning how to interpret.

In analyzing these signals we started to develop the basic signal processing and data display tools, and have even had the interesting experience of processing recordings obtained by Sue Cosens (Winnipeg) of sea mammal sounds.

These examples illustrate the way in which ocean acoustics research tends to lead to a multiplicity of new ideas and applications beyond the original area of immediate interest. The fundamental physical principles of acoustics, sound generation, propagation, scattering, signal detection, processing and display, are common to all applications of acoustics in the ocean. An open research environment, in which the full range of potential interests in acoustics can be freely pursued, seems especially beneficial for our department, in which acoustics plays such a pervasive role in our scientific and technological advancement.

Progress in Fisheries Acoustics

Robert Kieser
Pacific Biological Station
Nanaimo, B.C.

Abstract

Introduction

- Historical perspective
- Spectrum of biological parameters that can be measured

Typical fisheries acoustics measurements

- Fish finding
- Fish distribution and density measurements
- Survey design and biomass estimation
- Acoustic fish size and species recognition
- Biological studies
- Acoustic fence
- Acoustic tracking and sonar observations

Accuracy of fisheries acoustic data

- Hitting the bulls-eye
- Theoretical and experimental foundations
- The importance of a first rate measurement

Planning for the future

- Fish finding - Biological research - Fisheries acoustic research
- Research versus survey work
- Team approach: Acoustician - Biologist - Engineer - Technician
- Critical mass
- Centres of excellence, the need to focus the work

Traditional direct sampling methods such as purse seining, trawling or traps provide important information for fisheries research and management. These methods are indispensible when specimens are required. On the other hand, the use of echo sounders, sonars and other acoustic remote sensing techniques greatly improves the effectiveness of the traditional sampling methods and provides information that cannot be obtained otherwise.

During the last 15 years fisheries acoustic methods have evolved into an indispensible tool for fishermen, fisheries biologists and fisheries researchers. Acoustic theory and a wealth of experiments provide a solid foundation for using reliable echo sounders, sonar systems and instrumentation for fisheries acoustic research which are now available off the shelf.

The current generation of acoustic instruments can be used to locate fish and to measure fish distribution and density. Methods are also available to measure fish size and flux. These standard techniques are complemented by acoustic tags, passive listening, etc.

Traditional acoustic methods however are relatively ineffective in mixed species situations. They provide good overall information but do not yield species specific data.

Recent developments have brought fisheries acoustics work to a new threshold. Methods for 'acoustic species recognition' are now being developed. These have the potential to revolutionize fisheries work.

Results from several species recognition experiments have been presented at the International Symposium on Fisheries Acoustics, June 1987, Seattle, Washington. At this meeting J. Simmonds, Marine Laboratory, Aberdeen, Scotland and G. Rose, McGill University presented independent work that shows in excess of 90% species recognition on groups of three or four species. Our own work illustrates considerable structure in herring schools, information that also could contribute to acoustic species recognition.

The acquisition and evaluation of fisheries acoustic data may be as simple as using an echo sounder to detect the presence or absence of fish. Successful fisheries work and acoustic research, however, often involves a directed effort, a well formulated hypothesis and a team that includes biological, engineering, hydroacoustic, statistical and technical talents. A lack of team effort and 'critical mass' tends to produce mediocre results.

Good fisheries acoustic work has been done at DFO laboratories. To maintain our expertise and to reach new levels of excellence is a challenge to scientists and managers. To achieve this goal new directions and innovative changes are urgently required. This meeting will provide an ideal platform for discussions to start this process. The power of fisheries acoustic measurements is ready to reward this challenge.

References

Rose, G.A. and W.C. Legget. 1987. Hydroacoustic Classification of Cod, Capelin and Mackerel Schools by Target Strength and School Structure. International Symposium on Fisheries Acoustics, June 1987, Seattle.

Simmonds, J.E. and F. Armstrong. 1987. A Wide Band Echo Sounder: Measurements on Cod, Saithe, Herring and Mackerel from 27 to 54 kHz. International Symposium on Fisheries Acoustics, June 1987, Seattle.

Hydroacoustics in Biological Oceanography

Yvan Simard
Maurice Lamontagne Institute
Mont-Joli, Quebec

Abstract

In order to understand the fundamental mechanisms controlling the biological production on highly productive parts of the ocean, and to study the relationships of the 1st levels of the pelagic food-chain with the characteristics of an heterogeneous environment, a new generation of continuous sampling instruments was gradually developed in the 1970s to adequately resolve the complex patchy distribution of the organisms at sea.

One of these instruments was based on the use of sound scattering at high frequencies (>50 kHz) by small-size organisms in the range of $\lesssim 0.1$ to $\gtrsim 50$ mm. During the last decade, an increasing number of applications of hydroacoustics in biological oceanography appeared in the literature. The subjects vary from studies of the relationships between physical oceanography processors and the distribution of zooplankton, to studies of the link between the aggregations of zooplankton and the other trophic levels, from phytoplankton to whales. The present development in electronics, microcomputers and underwater acoustics is constantly improving the performance of this new and very powerful high technology, now available to ocean and fishery researchers.

The use of hydroacoustics in biological oceanography began in the mid 1960s when frequencies significantly higher than the standard 12 kHz became more common (Pieper 1983). The following decade was dedicated to the development and exploration of the method and during the last decade an increasing number of applications have been carried out. The interest of the field in that technique was related to the utilization of its high-resolution sampling capability, to study the nature and causes of the complex patchy distribution of zooplankton in the ocean (see Haury et al. 1978). This patchiness is a fundamental characteristic of the pelagic ecosystems (Steele 1978) and also an important source of variability in plankton studies. Since conventional samplers such as pumps and nets could not adequately resolve this patchiness at the scales that are important for understanding the correlations with physical processes or for predator/prey interactions (see Mackas et al. 1985), new sampling techniques were developed (Herman & Platt 1980). Hydroacoustics is one of them. Its main advantages over the other continuous samplers are: 1) the large volume sampled, 2) the recording of continuous information on two axes simultaneously, the horizontal and the vertical, and 3) the real-time display of usable information and the rapid processing of the data.

The sound energy backscattered by a zooplankter is a function of the density and sound speed contrast between the organism and the medium, the acoustic frequency and the size of the organism. Since zooplankters have a small size and most do not carry gas bubbles like fishes with swim bladder, the sound energy they backscatter is low. Six mathematical formulations have been used to model the sound scattering from zooplankton: 3 are derived from the model of scattering from a fluid sphere (see Piper and Holliday 1984), 2 describe the sound scattering from a fluid cylinder (Stanton in press), and the last one is an experimental model based on sound scattering from euphausiid crustaceans (Kristensen and Dalen 1986). All these models predict that the acoustic frequency must be sufficiently high to get measurable echo from a given size of organisms and that there is an optimal frequency which gives the largest echo, and which corresponds to a wavelength comparable to the size of the organism. The dependence of the backscattering strength of zooplankton on its size and the acoustic frequency that is described by the models, is exploited to use the echosounders as a size selective sampler according to their operating frequency (Greenlaw 1979). The utilisation of a series of frequencies can estimate the size spectrum of the animals. The optimal frequency for a few cm long zooplankters, like euphausiids and amphipods, varies from 25 to 250 kHz and for mm long copepods, the frequency range is from 200 kHz to 2 MHz (Clay and Medwin 1977).

High frequency (50 kHz) acoustics is presently used in zooplankton studies according to 4 methods of increasing complexity. The first one is qualitative and consists in using the acoustics for locating the zooplankton patches in real time in order to direct sampling or to study the variability (e.g. Haury et al. 1983). The second one uses the echo energy backscattered by a volume of water in relative units, calibrated with direct sampling, to estimate the biomass of zooplankton (e.g. Simard et al. 1986). The third one requires a well calibrated acoustic system to accurately measure the echo energy, which is transformed into biomass of the studied size class of zooplankters using its known or measured acoustic target strength (e.g. Pieper 1978, Sameoto 1983). The last one is the use of multifrequency acoustics signature of a volume of water and the scattering models, to calculate the biomass of zooplankton at various size classes (e.g. Greenlaw 1979).

The applications of hydroacoustics in biological oceanography concerned studies of: (1) distribution and behaviour of zooplankton, including the relation with the physical characteristics and processes, and (2) relations of the zooplankton aggregations with the other trophic levels, phytoplankton, fishes and whales. The first striking results of this high resolution sampler was to show how variable was the distribution of zooplankton both vertically and horizontally. This confirmed the ineptitude of conventional samplers to resolve the spatial patterns observed. The zooplankton was often concentrated in thin scattering layers, sometimes dispersed through all the water columns, absent in some areas while sometimes forming large dense aggregations very close by (e.g. Orr 1981, Sameoto 1983, Macaulay et al. 1984, Simard et al. 1986). Layering of zooplankton has been attributed to physical boundaries in temperature, salinity, density or underwater light levels (e.g. Piper 1977, Kampa 1975). Similar boundaries were also found to limit their horizontal distribution (e.g. Sameoto 1982). Small scale structures have been attributed to turbulent events changing the horizontal patterns or to internal waves which vertically displaced the horizontal layers (e.g. Orr 1981, Haury et al. 1983). Hydroacoustics has been used for mapping the distribution of the euphausiids on large scales (e.g. Sameoto 1976, Macaulay et al. 1984). It was also useful to show that these small crustaceans tend to aggregate in long narrow patches along some isobath contours at the margin of coastal shelves and at the head of deep channels, canyons and fjords (e.g. Simard et al. 1986, Simard & Mackas in prep.). This resulted in the formulation of new hypotheses integrating the deep water circulation and the behaviour of the animals to explain their aggregation mechanism. Some works have studied the relation of these aggregations with other trophic levels. Mapping surveys scattering layers of euphausiids and the abundance of phytoplankton chrorophyll a (Sameoto 1976). Other works have studied this phytoplankton/zooplankton interaction during diel vertical migrations of the scattering layers (Simard et al. 1985, 1986). It is common to observe schools of pelagic fishes close to the zooplankton scattering layer in areas of dense aggregations of zooplankton. In the vicinity of banks and shelves, the zooplankton layer often shoals and this rich concentration of food becomes available to the bottom fishes. Some feeding studies have shown that fishes caught with pelagic trawls into the scattering layer had their stomach full of euphausiids as well as those caught with bottom trawls in areas where the zooplankton scattering layer shoals (e.g. Pearcy et al. 1979, Falk-Petersen and Hopkins 1981). The interaction of zooplankton scattering layers with larger predators have also been studied at whale feeding grounds (e.g. Kriger and Wing 1986). The conclusions were that most whales were feeding on euphausiid scattering layers and that their distribution was directly related to the distribution of euphausiid concentrations. The variations in the utilisation of the feeding ground from year to year was attributed to variations in prey abundances which coincided with variations in oceanographic conditions. Other works on the whale/euphausiid interaction have described the diving and ventilation behaviour of the whales in relation with the depth of the euphausiid layer (Dolphin 1987).

The future development of hydroacoustics in biological oceanography will be related to the application of the method to a wider size spectrum than the present size range of 1 mm to 5 cm. The possibility of size classification of the animals with multifrequency acoustics should be more exploited, for mm-long organisms, with acoustic profilers (e.g. Pieper and Holliday 1984), and for cm-long organisms, with conventional surface echosounding (e.g. Greenlaw 1979). Another development that must be done is related to the sharing of space by zooplankton and fishes. This fish/zooplankton interaction sometimes significantly affects the ability of the method to estimate the zooplankton biomass. It is however a subject of interest which needs to be studied. Stanton and Clay (1986) have proposed to look at the probability distribution of the echos to solve this problem. The utilisation of such a method should be tried and new ones should be developed.

The use of hydroacoustics in biological oceanography is only at its first stage, but an increasing number of workers in that field are adopting it. With the development of new hardware and software the information gained by this technique will improve considerably, as well as its ease of use. This development requires the contribution of a multidisciplinary team of physicists, engineers, and biologists.

References

Clay, C.S. and H. Medwin. 1977. Acoustical Oceanography: Principles and Applications. John Wiley & Sons, New York. 554 pp.

Dolphin, W.F. 1987. Prey Density and Foraging of Humpback Whales *Megaptera novaeangliae*. Experimentia 43: 468-471.

Falk-Petersen, S. and C.C.E. Hopkins. 1981. Zooplankton Sound Scattering Layers in North Norwegian Fjords: Interactions Between Fish and Krill Shoals in a Winter Situation in Ullsfjorden and Oksfjorden. Kieler Meeresforsch. Sonderh. 5: 191-201.

Greenlaw, C.F. 1979. Acoustical Estimation of Zooplankton Populations. Limnol. Oceanogra. 24: 226-242.

Haury, L.R., et al. 1978. Patterns and Processes in the Time-Space Scales of Plankton Distributions, pp. 277-327. In J.H. Steele (ed.) Spatial Pattern in Plankton Communities. Plenum Press, New York.

Haury, L.R., et al. 1983. Tidally Generated High-Frequency Internal Wave Packets and Their Effects on Plankton in Massachusetts Bay. J. Mar. Res. 41: 65-112.

Herman, A. and T. Platt. 1980. Meso-scale Spatial Distribution of Plankton: Co-Evolution of Concepts and Instrumentation, pp. 204-225. In M. Sears & D. Merriman (eds.) Oceanography The Past. Springer-Verlag, New York.

Kampa, E.M. 1975. Observations of a Sonic-Scattering Layer During the Total Solar Eclipse, 30 June 1973. Deep Sea Res. 22: 417-423.

Krieger, K.J. and B.L. Wing. 1986. Hydroacoustic Monitoring of Prey to Determine Humpback Whale Movements. U.S. Dept. of Commerce NOAA Tech. Mem., NMFS F/NWC-98, 62 pp.

Kristensen, A. and J. Dalen. 1986. Acoustic Estimation of Size Distribution and Abundance of Zooplankton. J. Acoust. Soc. Am. 80: 601-611.

Macaulay, et al. 1984. Acoustic Characterisation of Swarms of Antartic Krill (*Euphausia superba*) from Elephant Island and Bransfield Strait. J. Crust. Biol. 4: 16-44.

Mackas, D.L. et al. 1985. Plankton Patchiness: Biology in the Physical Vernacular. Bull. Mar. Sci. 37: 652-674.

Orr, M.H. 1981. Remote Acoustic Detection of Zooplankton Response to Fluid Processes, Oceanographic Instrumentation, and Predators. Can. J. Fish. Aquat. Sci. 38: 1096-1105.

Pearcy, W.G. et al. 1979. Feeding Habit of Cod, Capelin and Herring in Balsfjorden, Northern Norway, July-August 1978: The Importance of Euphausiids. Sarsia 64: 269-277.

Pieper, R.E. 1979. Euphausiid Distribution and Biomass Determined Acoustically at 102 kHz. Deep-Sea Res. 26: 687-702.

Pieper, R.E. 1977. Some Comparisons Between Oceanographic Measurements and High-Frequency Scattering of Underwater Sound, pp. 667-677. In N.R. Andersen and B.J. Zahuranec (eds.) Oceanic Sound Scattering Prediction. Plenum Press, New York.

Pieper, R.E. 1983. Quantitative Estimates of Euphausiid Biomass Determined by High-Frequency Acoustics. Biol. Oceanogr. 2: 133-149.

Pieper, R.E. and D.V. Holliday. 1984. Acoustic Measurement of Zooplankton Distributions in the Sea. J. Cons. Int. Explor. Mer 41: 226-238.

Sameoto, D.D. 1976. Distribution of Sound Scattering Layers Caused by Euphausiids and Their Relationship to Chlorophyll Concentrations in the Gulf of St. Lawrence Estuary. J. Fish. Res. Board Can. 33: 681-687.

Sameoto, D.D. 1982. Zooplankton and Micronekton Abundance in Acoustic Scattering Layers on the Nova Scotian Slope. Can. J. Fish. Aquat. Sci. 39: 760-777.

Sameoto, D.D. 1983. Euphausiid Distribution in Acoustic Scattering Layers and Its Significance to Surface Swarms. J. Plankton Res. 5: 129-143.

Simard, Y. et al. 1985. In Situ Twilight Grazing Rhythm During Diel Vertical Migrations of a Scattering Layer of Calanus finmarchicus. Limnol. Oceanogr. 30: 598-606.

Simard, Y. et al. 1986. Diel Vertical Migrations and Nocturnal Feeding of a Dense Coastal Krill Scattering Layer (Thysanoessa raschi and Meganyctiphanes norvegica)in Stratified Surface Waters. Mar. Biol. 91: 93-105.

Simard, Y. et al. 1986. Aggregation of Euphausiids Along a Coastal Shelf in An Upwelling Environment. Mar. Ecol. Prog. Ser. 32: 203-215.

Simard, Y. and D.L. Mackas. In prep. Aggregation of Euphausiids on the Continental Shelf of Vancouver Island.

Stanton, T.K. In press. Sound Scattering by Cylinders of Finite Length. J. Acoust. Soc. Am.

Stanton, T.K. and C.S. Clay. 1986. Sonar Echo Statistics as a Remote-Sensing Tool: Volume and Sea Floor. IEEE J. Ocean. Eng. OE-11, 1: 79-96.

Steele, J.H. 1978. Spatial Pattern in Plankton Communities. Plenum Press, New York. p. 470.

Acoustics in Physical Oceanography

David Farmer
IOS
Sidney, B.C.

Abstract

Physical oceanographers are starting to recognize the immense potential for scientific insight to be gained from an acoustic view of the ocean. One of the simplest and most effective approaches is flow visualization using high frequency backscatter to yield images of internal waves, shear flow instabilities, hydraulic processes and coherent structures in turbulence. Analysis of the Doppler spectrum allows measurement of the velocity field; combined with more traditional approaches these two techniques provide powerful tools for studying density stratified flows in straits and coastal areas. If a sonar is pointed upwards it can be used to study processes at the air-sea interface. New observations with multi-frequency backscatter, video photography and ambient sound, reveal a wealth of detail in the structure of wave-breaking, bubble clouds and organized features in the upper ocean boundary layer. The naturally occurring sound can be used to study wave-breaking, wave periodicity and group structure; sidescan sonar has provided unambiguous evidence of Langmuir Circulation.

Ambient sound in the Arctic contains information on the behaviour of ice: thermal tension cracking, and large scale lead formation, break-up and ice-floe interaction. Detailed analysis of individual cracking events should help us to use the ambient sound more effectively for rheological studies of the ice cover.

Acoustic scintillation, the modification of sound as it travels through the ocean by small scale irregularities in temperature and salinity, provides a basis for measuring flow speed and turbulence. Two-dimensional sets of projectors and hydrophones allow profiling of the flow along the acoustic path and detection of anisotropic features, such as fronts, advected past the array.

Introduction

Acoustic methods can provide new and effective ways of studying the ocean. Figure 1 shows some of the process we are now, or soon hope to look at with these new techniques. Moreover, the items shown here are only a small sample. Oceanographers are just starting to realise the value of acoustic methods and the deep insight they can provide to dynamical processes. This survey focusses on some of the ideas we have been exploring in the Ocean Acoustics Graduate Studies group at IOS. Time and space preclude a comprehensive survey; indeed, I cannot even include here a discussion of all of our own activities, let alone the important and interesting contributions of others. The acoustics of physical oceanography is in a rapid state of development. This discussion is intended to provide a representative sample based on personal experience. Examples are included from each of the 3 categories of acoustic remote sensing (Figure 2).

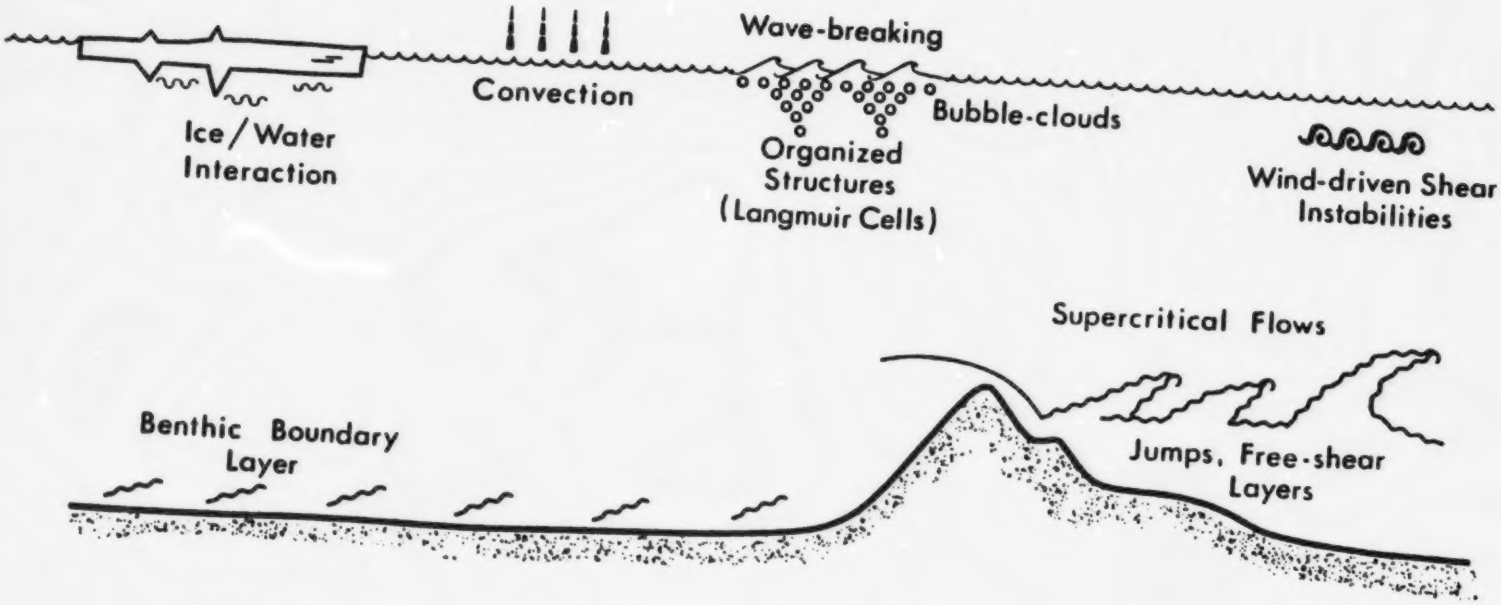

Wave-breaking
Convection
Ice/Water Interaction
Bubble-clouds
Organized Structures (Langmuir Cells)
Wind-driven Shear Instabilities
Supercritical Flows
Benthic Boundary Layer
Jumps, Free-shear Layers

Figure 1

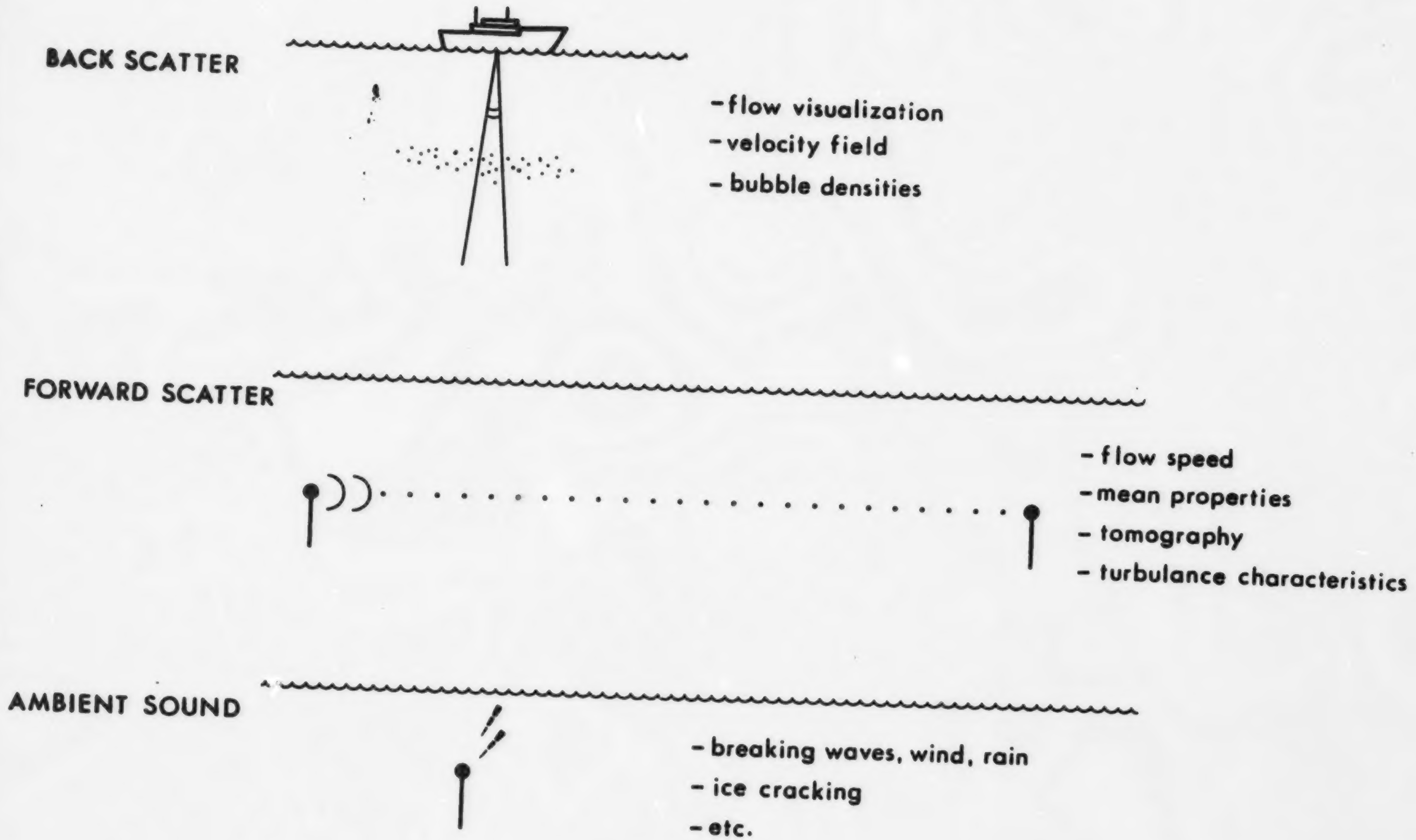

BACK SCATTER
-flow visualization
-velocity field
- bubble densities
FORWARD SCATTER
- flow speed
-mean properties
- tomography
- turbulance characteristics
AMBIENT SOUND
- breaking waves, wind, rain
- ice cracking
- etc.

Figure 2

Back Scatter

The simplest application of acoustics is the use of a high frequency echo-sounder. Run the ship slowly and turn up the gain; bubbles, microstructure and biota provide the tracers and marvellous images will result. When combined with other types of measurement, the additional view to be gained by high frequency echo-sounding will deepen your insight immeasurably. Figure 3 shows flow over the sill in the Strait of Gibraltar. The interface between Atlantic and Mediterranean water is clearly seen. Temperature (Figure 4) and acoustic Doppler velocity (Figure 5) profiles, intended as overlays to the acoustic image, provide supporting data. When put together, these different measurements provide a basis for quantitative statements about this important oceanographic exchange.

Forward Scatter

When sound travels through a heterogeneous fluid such as the ocean it is distorted. Figure 6 shows a computer simulation of an initially plane wave travelling horizontally as it is progressively perturbed by small scale random temperature structure. (Internal waves would produce a different kind of perturbation.) We have explored this idea using an array of acoustic projectors on one side of a tidal channel and an array of hydrophones, facing them, on the other side (Figure 7). The scintillation data can be used in various ways. Figure 8 shows a comparison of flow speed deduced from translation of the scintillation pattern, with measurements by recording current meter. Other applications involve the use of a two dimensional representation of the scintillation structure, to study turbulence characteristics.

Ambient Sound

Natural sound generated by processes at the ocean surface can be observed with a simple hydrophone and recorder. The task of interpreting the signal becomes a fascinating detective story, requiring an understanding of the various mechanisms of sound generation and propagation. Figure 9 shows the sound level recorded at 3 different depths. There is much more variability near the surface. This change in variability with depth can be explained with a computer model of sound sources, representing the breaking waves, moving across the ocean surface. The model allows us to use the data to infer the mean density of breakers and other properties. Breaking events turn out to be closely modulated by the wave period; this too, we can derive from the acoustic signal.

In the Arctic, the sound of ice cracking can be detected with arrays of hydrophones (Figure 10). The resulting signals (Figure 11) bear an uncanny resemblance to seismic records of earthquakes. In fact, we are finding that an adaptation of earthquake theory provides an excellent basis for interpreting the results. The sound of ice-cracking should allow us to make useful inferences about the condition of the ice in navigable waterways in the Arctic.

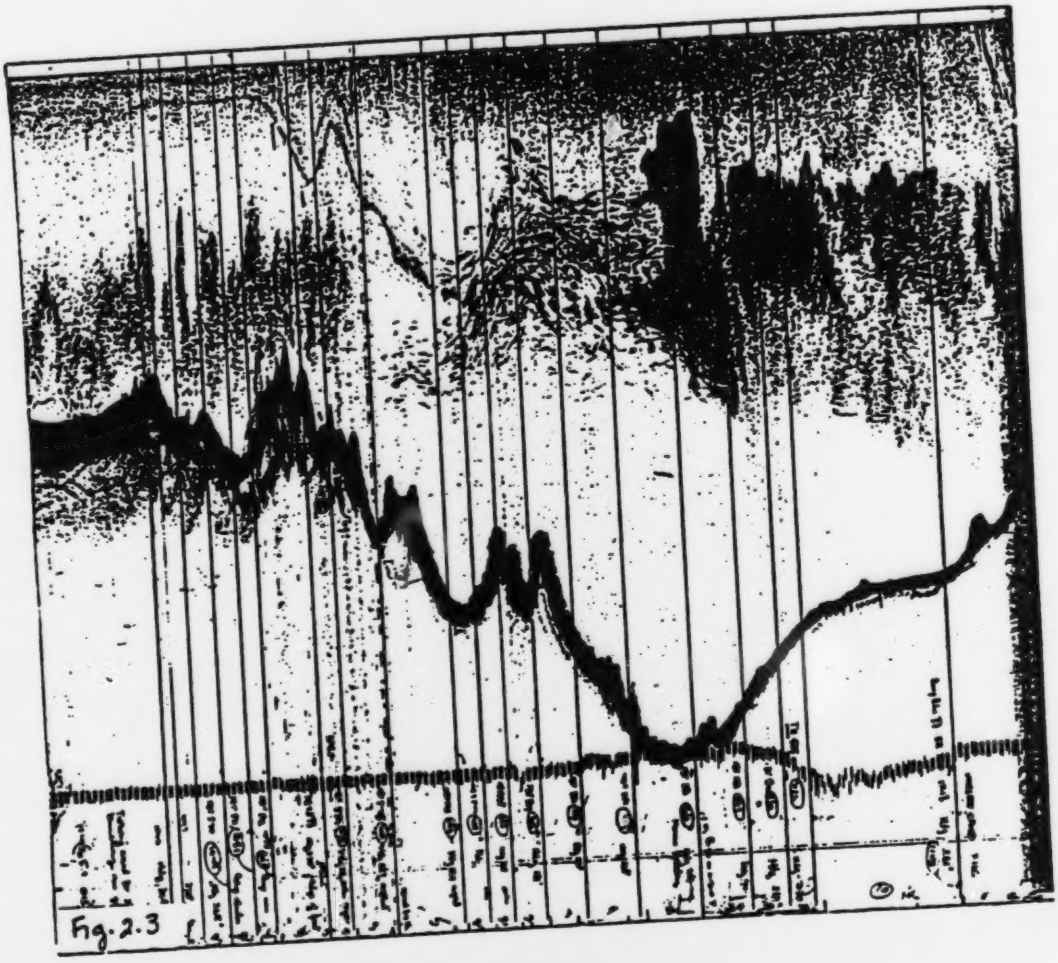


Figure 3

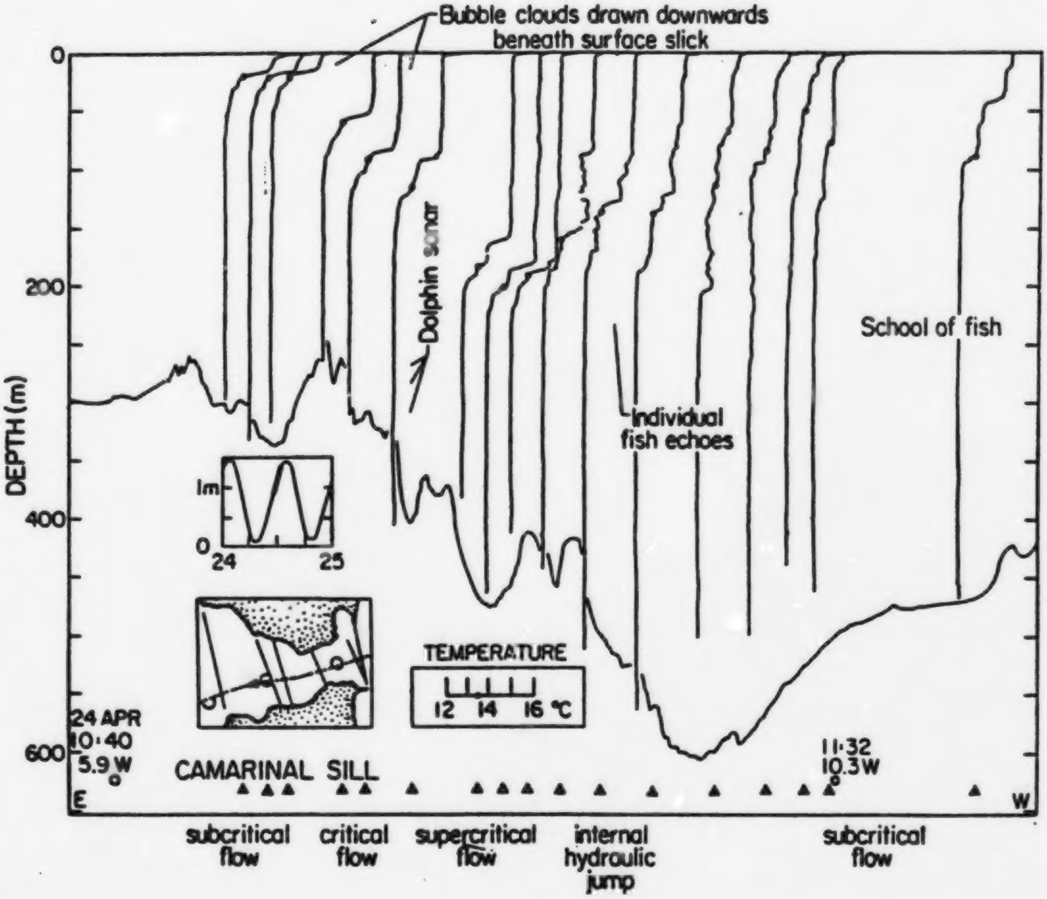

Bubble clouds drawn downwards beneath surface slick
DEPTH (m)
0
200
400
600
Dolphin sonar
Individual fish echoes
School of fish
1m
0
24
25
TEMPERATURE
12
14
16 °C
24 APR
10:40
5.9 W
CAMARINAL SILL
11:32
10.3 W
E
W
subcritical flow
critical flow
supercritical flow
internal hydraulic jump
subcritical flow

Figure 4

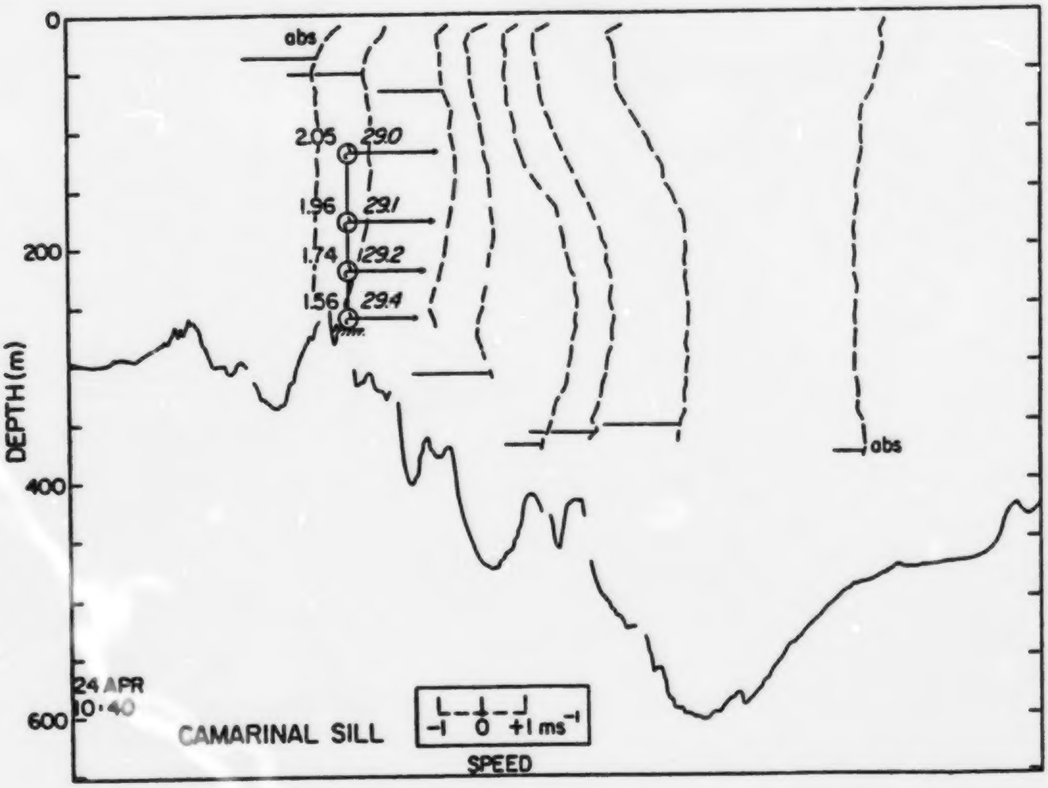

0
200
400
600
DEPTH (m)
abs
2.05
29.0
1.96
29.1
1.74
129.2
1.56
29.4
abs
24 APR
10·40
CAMARINAL SILL
-1
0
+1 ms^{-1}
SPEED

Figure 5

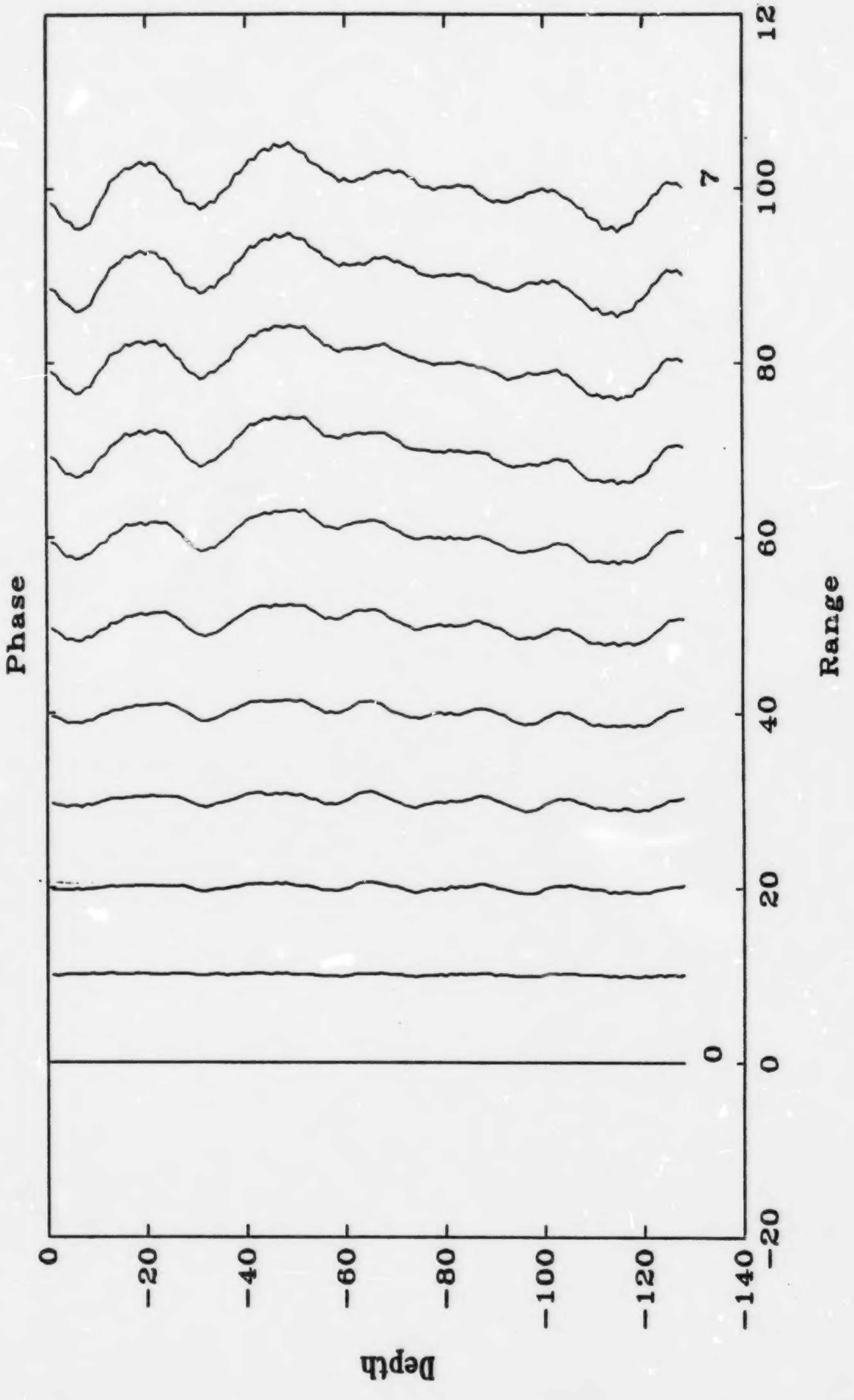
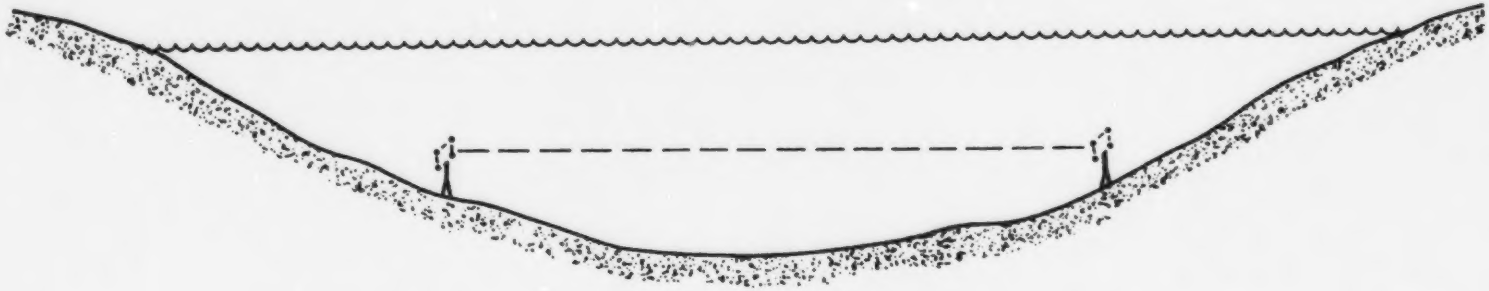

Phase
Range
Depth
0
7
-20
0
20
40
60
80
100
12
0
-20
-40
-60
-80
-100
-120
-140

Figure 6

ACOUSTIC SCINTILLATION - Turbulence in a coastal environment. (*D. Farmer*)



4 Transmit, 4 Receive Transducers (1m square array)

Range ~ 700m

Frequency 70kHz

Angle-of-Arrival (AOA) measured in vertical and horizontal

(Rapid fluctuations are ~ ± 0.05°)

Figure 7

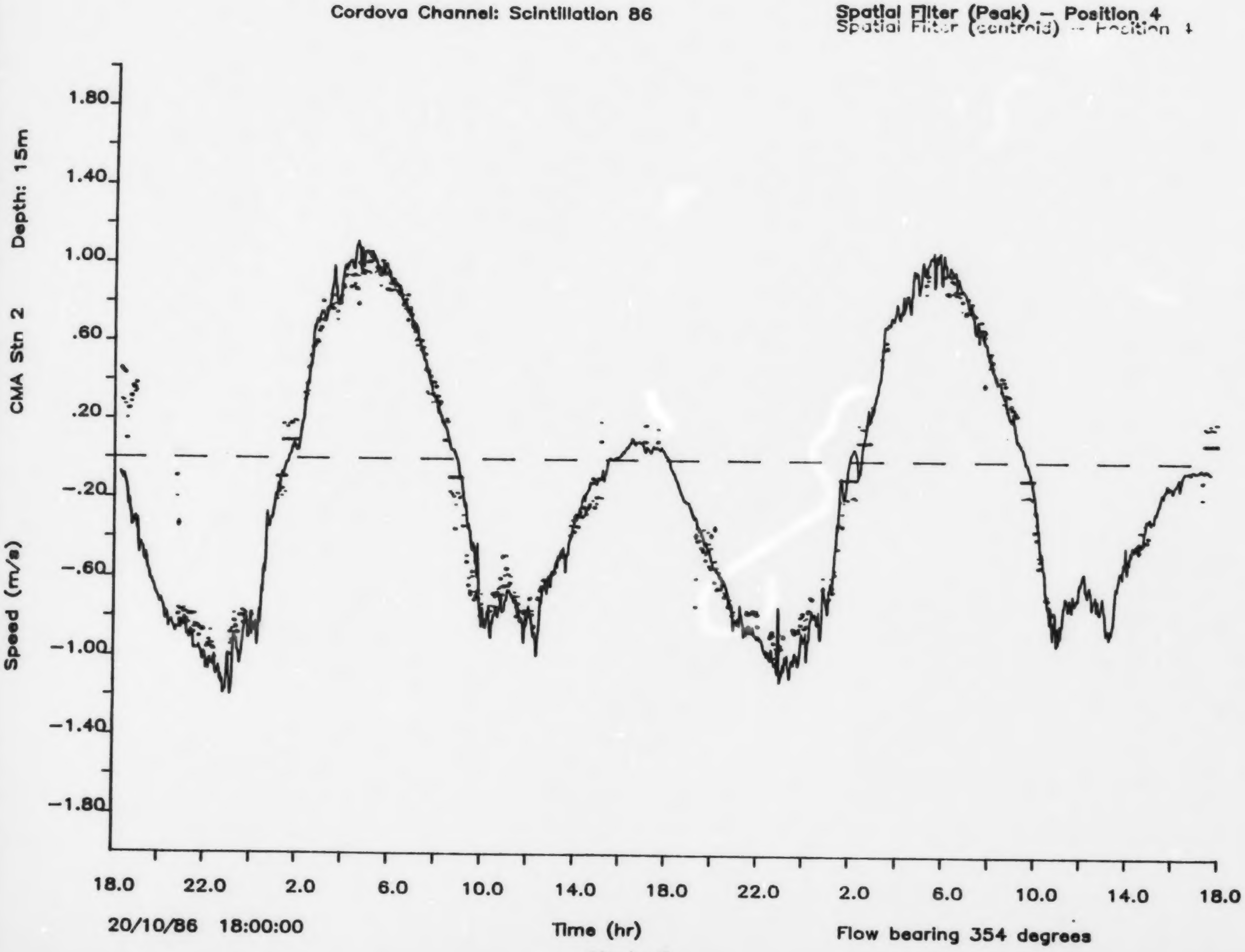

Cordova Channel: Scintillation 86
Spatial Filter (Peak) — Position 4
Spatial Filter (centroid) — Position 4
Depth: 15m
CMA Stn 2
Speed (m/s)
1.80
1.40
1.00
.60
.20
-.20
-.60
-1.00
-1.40
-1.80
18.0
22.0
2.0
6.0
10.0
14.0
18.0
22.0
2.0
6.0
10.0
14.0
18.0
20/10/86 18:00:00
Time (hr)
Flow bearing 354 degrees

Figure 8

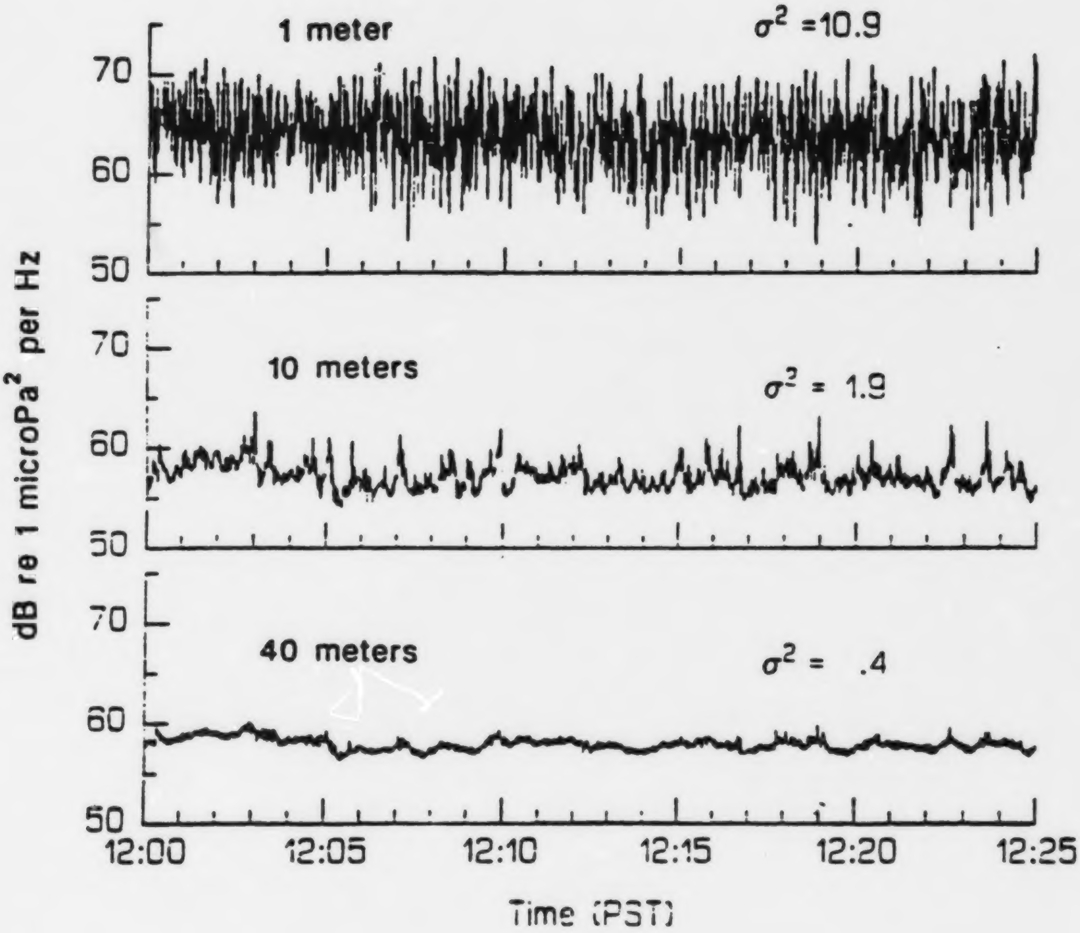

1 meter
σ^2 =10.9
10 meters
σ^2 = 1.9
40 meters
σ^2 = .4
70
60
50
dB re 1 microPa^2 per Hz
12:00
12:05
12:10
12:15
12:20
12:25
Time (PST)

Figure 9

Study of cracks in ice using multi-hydrophone array. (*D. Farmer*)

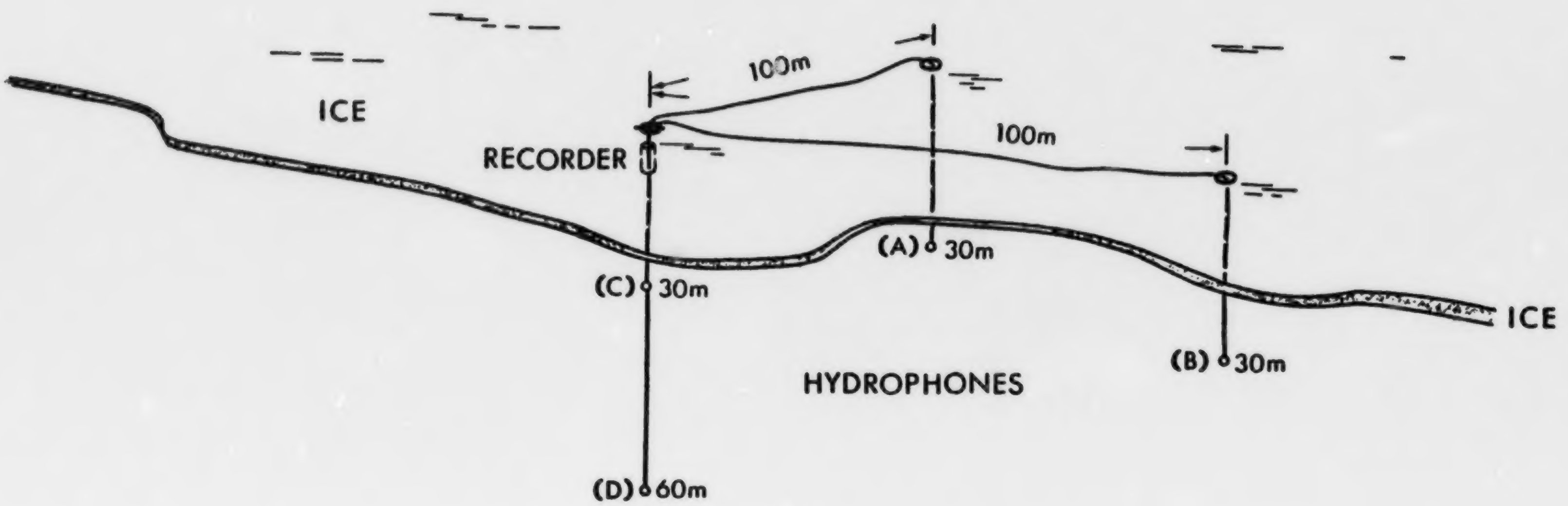
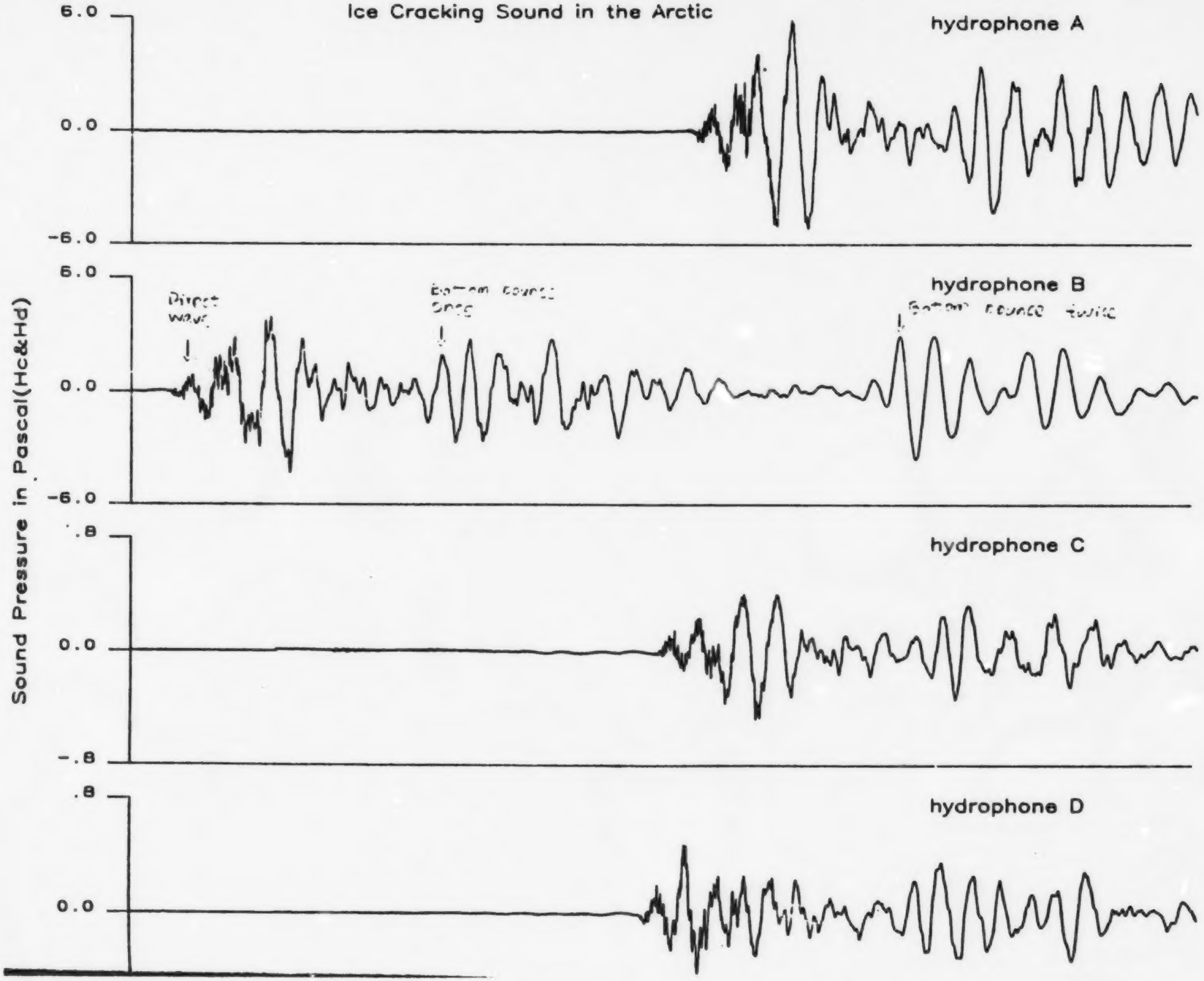

ICE
RECORDER
100m
100m
(A) 30m
(B) 30m
(C) 30m
(D) 60m
HYDROPHONES
ICE

Figure 10



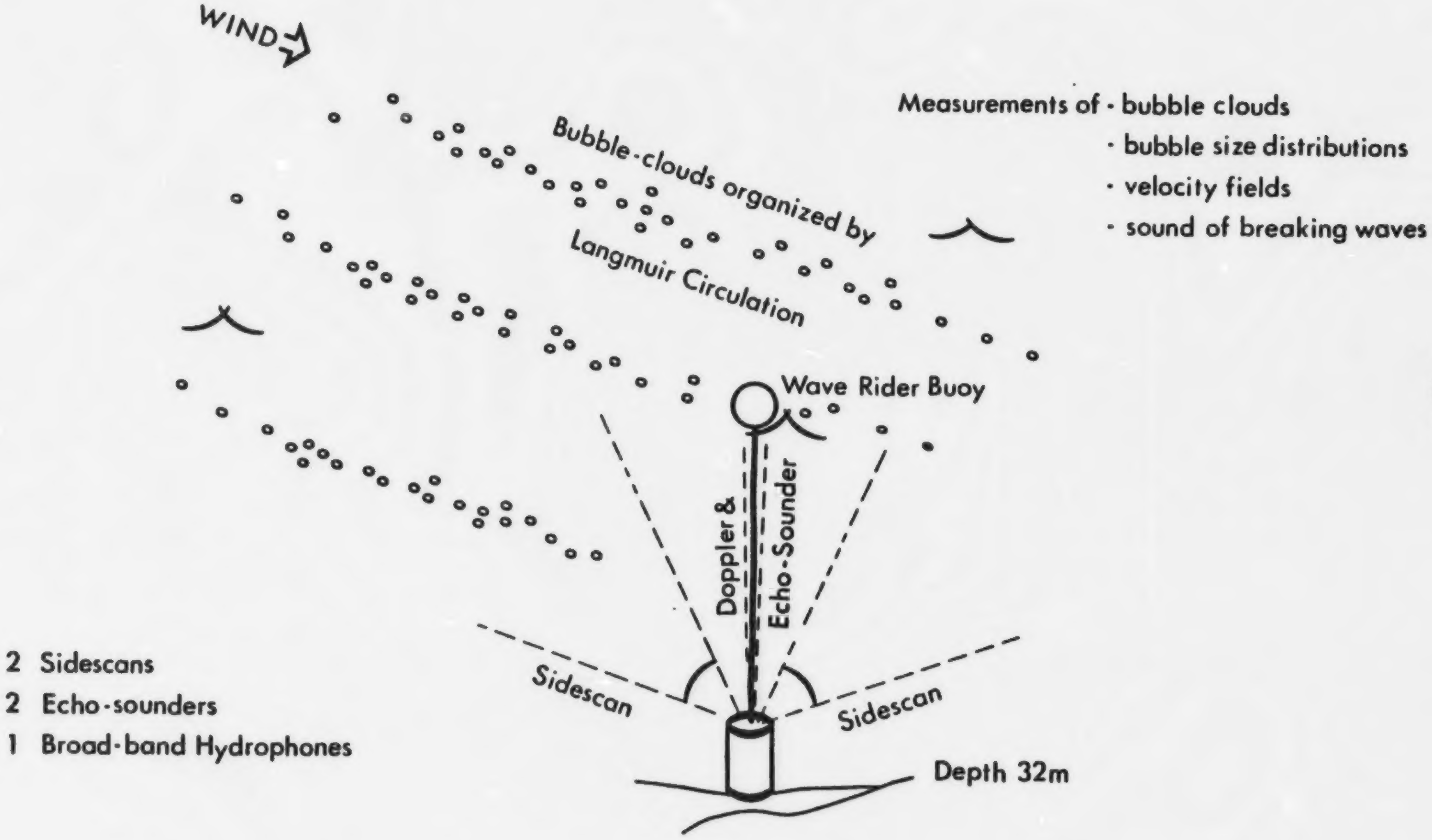
Event 4 acoustic signal   Figure 11

A Combination of Techniques

Finally, in Figure 12, we show an instrument we have used to exploit both active and passive sonar techniques in the study of the ocean surface. The instrument is supported by a rubber cord about 30m below the surface. Isolated from much of the wave action, it nevertheless records backscatter at different frequencies to study bubble populations, vertically oriented Doppler to measure velocity, sidescan sonar to look at the two-dimensional structure of the bubble clouds, and a hydrophone to detect the ambient sound field. Controlled by a microcomputer, it can be switched on and off at will, or externally controlled by an acoustic signal from a ship. It has an endurance equivalent to 80 hours of continuous running. An initial test in October 1987 yielded many interesting observations including unambiguous evidence of Langmuir Circulation, which systematically orient the bubble clouds into long lines spaced some 10m apart and following the direction of the wind.

The exploration of the ocean using underwater sound is still at a very early stage of development, but it is already clear that many insights are to be gained with these powerful techniques. The future development of physical oceanography will surely owe much to these remote sensing methods that give us this unexpected, and revealing, acoustic view of the ocean.

ACOUSTIC DRIFTER STUDIES of upper ocean boundary layer. (*D. Farmer*)



WIND
Bubble-clouds organized by
Langmuir Circulation
Wave Rider Buoy
Doppler &
Echo-Sounder
Sidescan
Sidescan
Depth 32m

Measurements of · bubble clouds
· bubble size distributions
· velocity fields
· sound of breaking waves

2 Sidescans
2 Echo-sounders
1 Broad-band Hydrophones

Figure 12

A Review of Acoustic Applications in the Canadian Hydrographic Service

G.R. Douglas
Canadian Hydrographic Service
Ottawa, Ontario

Abstract

The use of acoustic measurements is a fact of everyday life for the practicing hydrographer. The application of acoustics to hydrography and the associated technology changed very little from the introduction of the echo sounder in 1929 to the early 1960s. With the advent of solid state devices for transmitting and detecting underwater acoustic signals, the efficiency and reliability of echo sounders began to increase. With the introduction of microprocessors for the logical control and processing of acoustic signals, quantum leaps in terms of the application of acoustics to hydrographic problems began to take place. The range of these applications will be reviewed in the paper.

Given the proliferation of marine acoustic applications, a discussion on the level of understanding and expertise available versus what is required in the Canadian Hydrographic Service will be presented. Proposals for the enhancement of this understanding will be presented for the consideration of the workshop.

I'm very pleased to be able to make a presentation to you on this very important subject of hydroacoustics and its applications in the field of hydrography. My remarks will be of a very general nature as many of the presentations later in the Workshop will deal with specific problems.

There is little doubt that hydroacoustics has been a neglected child in our investigation and study of the oceans. This is somewhat amazing and perhaps even frightening as acoustic techniques are generally involved in many of the basic measurements that are made during these investigations. Therefore, I am very pleased that this Workshop is taking place because I think it signals a recognition of this problem and hopefully, a new thrust in the understanding of hydroacoustics and its applications. Another point that I believe is important from a Science organizational point of view is that hydroacoustics is a common thread that runs through all 3 work activities as evidenced by the range of presentation here today.

Why has hydroacoustics become a neglected child? It is rather surprising because the application of acoustics to every day problems is common place. For example:

- the range finder on some cameras
- the tank levels at your local brewery
- the tire pressure in new automobiles
- road roughness for suspension adjustments

We have not taken the same interest in acoustics as we have in, say, positioning or navigation. For a number of years, we have studied and investigated all of the problems of positioning at sea and have done a rather good job. So we have done good work in the X and Y components but failed to take the same interest in the Z component.

Why get excited now - we haven't been doing badly. There are a few reasons:

- In recent litigation against the Crown we are now being questioned and indeed questioning ourselves about the Z measurement, whereas, previous questioning was generally restricted to the X, Y coordinates.
- The sophistification of the systems we are now starting to acquire, is increasing at a great rate - for example, the vertical sweep system fitted on the C.S.S. FCG SMITH or the new multibeam swath system that is about to be installed in the C.S.S. LOUIS M LAUZIER in the Québec Region. We must understand these systems to understand the data.
- Perhaps it is the onslaught of these systems and the large amounts of data that are having the greatest influence. We suddenly have to worry about handling so much data - about having to compress all of the data into a form that is useable by the hydrographer or mariner.
- Positioning is rather vital for referencing all types of data as well as the acoustic measurements.
- The usefulness of most other measurements depend to a great extent on knowing where they occur on the surface of this Earth.
- Another factor is the medium in which we are trying to operate with acoustics - it is so variable in its physical characteristics - it is so noisy - but it is so important.
- Finally there is complacency. We turn on the echo sounder or sonar and we generally get results. But what are we getting? Yes, we do some rather rudimentary calibration that gives us some assurance that we are not far wrong. Is that good enough?

The quantity of data is rather large. For example, the swath system on the FCG SMITH is in the order of 2.5 million measurements/hr. The new swath multiple beam systems produces data at a rate of about ½ million data points per hour.

So, this really brings us to signal processing. We need to be able to apply some of the more sophisticated bottom detection techniques. The newer systems are indeed applying some of these techniques but the hydrographer must understand these techniques and their effect on the data.

The importance of the computing horse power cannot be underestimated. There are now sonar systems that use 64 microprocessor, parallel processing hardware.

What to do about all this? Where should we be going in an attempt to solve our problems.

- Well, this workshop is an excellent first start. We must talk with our colleagues/share our problems and really identify the magnitude of our state of affairs. Maybe our problems in Science as a whole are not as big as we might think - I believe the opposite to be true.

- I believe we have to train or reorient some of our people in acoustics. We must talk to the Universities, the oceanographic departments, survey science departments, the physics departments once we understand the scope of problem, to ensure that new graduates are versed in hydroacoustics.

- Lastly, we may want to consider establishing a CODE in hydroacoustics. Certainly, I believe such a CODE would serve the needs of the Department, however, the concentration of a CODE in a particular location may have some practical limitations. Or, we may want to consider an enhanced level of coordination through a number of mechanisms that are available.

I conclude by re-emphasizing the importance of hydroacoustics not only to hydrography but to all of the Science Sector. We must direct our attention to the identification of the magnitude of our problem and to develop realistic solutions.

The Application of Hydroacoustic Techniques to the Study of Marine Mammals

Susan E. Cosens
Freshwater Institute
Winnipeg, Manitoba

Abstract

The Department of Fisheries and Oceans, Central and Arctic Region is currently involved in three studies that use hydroacoustic techniques to acquire information about marine mammals. As an alternative to expensive aerial surveys, M. Kingsley has been investigating the use of vocal signals as a tool to index local numbers of narwhal. The study began by using passive recordings of vocal signals to estimate vocal activity relative to numbers. Current research is acquiring data on how vocalizations vary according to ongoing activity and group composition. A three-hydrophone array permits localization and identification of vocalizing groups so data on activity and group composition can be collected. In response to concern about the effects of ship traffic on marine mammals, S. Cosens has been studying how the behaviour and distribution of narwhal and beluga whales vary in response to underwater ship noise. Underwater ambient noise has been recorded to assess changes in noise levels experienced at the Admiralty Inlet ice edge during ship activity. Vocalizations of narwhal and beluga are also being recorded to assess the potential for masking of communication signals by ship noise. Estimation of source levels of vocalizations is essential to this study of masking effects. Finally, in an attempt to determine why narwhal and beluga respond differently to disturbance, we plan to use sonar to collect data on behavioural differences between the species. Management of marine mammals requires data on the abundance and distribution of food resources that support populations. R. Crawford is presently using sonar to study fish exploited by beluga whales in the Canadian Arctic. The presentation will describe the techniques currently being used, identify problems associated with these techniques and discuss research needs.

Introduction

Reasons for development of hydroacoustic techniques for use on marine mammals include:

1) vocal activity may be a useful indicator of population numbers;
2) ship noise may interfere with normal behaviour and communications;
3) knowledge of abundance and distribution of marine mammal prey may aid with management of marine mammal populations.

The report will discuss the methods currently being used, problems associated with these methods and needs for new techniques.

Marine Mammal Census

In 1984 DFO, Central and Arctic Region began a study of narwhal (Monodon monoceros) in Tremblay Sound, N.W.T. to assess whether vocal activity could be used as an index of absolute numbers of individuals. This method requires that one compare visual and acoustic counts and know which animals are vocalizing and what general activities are associated with vocalizations. These data are needed to adjust counts for population composition and activity.

Sounds were initially recorded with a single hydrophone and a reel-to-reel tape recorder. Counts of whales and observations of their activity were recorded at the same time as vocalizations. This method is limited because we do not know the distance over which narwhal signals propagate or the direction from which they arrive so we cannot accurately associate recorded vocalizations with specific groups or individuals.

A three-sonobuoy array is presently being adapted for use with narwhal. Incoming signals are recorded simultaneously on three sonobuoys. Differences in arrival time at the sonobuoys are used to triangulate the signal source. The system can localize only tonal FM signals and such signals make up a minority of the vocal repertoire of narwhal. The frequency bandwidth is also relatively narrow, being limited to about 6 kHz. The system is being modified to overcome these problems.

Marine Mammals/Vessel Interactions

The study began in Lancaster Sound in 1986. Activities include documenting changes in distribution and behaviour of narwhal and beluga (Delphinapterus leucas) in response to ship noise, describing changes in the acoustic environment due to the addition of ship noise, recording and describing acoustic communication signals of narwhal and beluga and studying behavioural differences between the two species.

Recordings have been made with a single hydrophone and reel-to-reel tape recorder. Activity of whales was recorded concurrently with vocalizations. We not only have to identify vocalizing groups but also prevent confusing beluga and narwhal vocalizations. As a single hydrophone is of limited usefulness, a parabola has been added to the hydrophone to facilitate focusing on specific groups and reduce contamination of species specific recordings. The present parabola design is noisy because of cable flutter and needs to be modified.

A hydrophone array is needed to accurately localize vocalizations and to estimate source levels of vocalizations so we can estimate their propagation distance. We will require a system that can localize both AM and FM signals. With this information we can begin to assess the effects of masking of whale communication by ship noise.

A playback system using a J-9 broadband transducer has been developed. It will not "mimic" a ship but will provide sufficient noise output to test responses to disturbance. It will also be used to test responses of whales to conspecific sounds.

An echo integrater and dual beam target strength analyzer is going to be used to look for narwhal and beluga diving under ice and to search for patches of prey. We hope to be able to collect comparative data on foraging behaviour. The technique was tested in 1986 and larger scale testing is planned for 1988.

Stock Assessment of Marine Mammal Food Resources

The study, begun in 1985, assesses abundance, distribution and behaviour of fish in areas frequented by beluga whales. Small bays in the eastern Arctic (around Resolute Bay) and near-shore areas in the Beaufort Sea (off Banks Island) are being sampled.

The echo integrator and dual beam target strength analyzer permits localization and identification of fish schools and invertebrates both under the ice and in open water. The study previously used a 200 kHz signal which can pick up small targets but has a limited range. In 1988, 120 kHz will be tested. This frequency will provide a better range, but poorer resolution of smaller targets such as amphipods.

General Conclusions

Development of hydroacoustic techniques for use in marine mammal research by DFO parallels developments elsewhere. Each application is unique, however, and methods must be modified accordingly.

References

Beeman, K., C.W. Clark and W.T. Ellison. 1985. Acoustic Tracking of Migrating Whales. Horizon No. 9.

Clark, C.W. 1980. A Real-Time Direction Finding Device for Determining the Bearing to the Underwater Sounds of Southern Right Whales, Eubalaena australis. J. Acoust. Soc. Am. 68: 508-511.

Clark, C.W., W.T. Ellison and K. Beeman. 1986. A Preliminary Account of the Acoustic Study Conducted During the 1985 Spring Bowhead Whale, Balaena mysticetus, Migration Off Point Barrow, Alaska. Rep. Int. Whal. Commn. 36: 311-326.

Ko, D., J.E. Zeh, C.W. Clark, W.T. Ellison, B.D. Krogman and R. Sonntag. 1986. Utilization of Acoustic Location Data in Determining a Minimum Number of Spring-Migrating Bowhead Whales Unaccounted for by the Ice-Based Visual Census. Rep. Int. Whal. Commn. 36: 325-338.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack and J.E. Bird. 1984. Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities or Migrating Gray Whale Vehavior, Phase II: January 1984 Migration. Rep. prep. by Bolt Beranek and Newman Inc. for U.S. Department of the Interior.

Malme, C.I., P.R. Miles, P. Tyack, C.W. Clark and J.E. Bird. 1985. Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Feeding Humpback Whale Behavior. Rep. prep. by BBN Laboratories Incorporated for U.S. Department of the Interior.

Stirling, I., H. Cleator and W. Calvert. 1982. Underwater Vocalizations As A Tool For Studying the Distribution and Relative Abundance of Wintering Pinnipeds in the High Arctic. Rep. prep. by C.W.S. (Edmonton) for the Arctic Pilot Project and the Arctic Islands Operating Advisory Committee.

Tyack, P. 1983. Differential Response of Humpback Whales, *Megaptera novaeangliae*, to Playback of Song or Social Sounds. *Behav. Ecol. Sociobiol.* 13: 49-55.

Watkins, W.A. and C.A. Goebel. 1984. Sonar Observations Explain Behaviors Noted During Boat Maneuvers for Radio/Tagging of Humpback Whales (*Megaptera novaeangliae*) in the Glacier Bay area. Cetology 48: 1-8.

Discussion on State of the Art Reviews

The intent of the first day of the Workshop was to provide participants, particularly DFO senior managers, with an overview of the concepts, technologies and issues in the various hydroacoustic fields. Highlights of the ensuing discussion on these overview papers.

1. Terminology: It was noted that there was little standardization in terminology and/or units in the field of hydroacoustics. It is very difficult to analyze the results of other researchers, or to intercompare research results, if: standard terminology, reference levels or units are not used. It was suggested that some of the confusion is a holdover from U.S. military involvement in acoustic R&D and applications. However, it was noted that, since this was a global problem, it would likely be a fruitless exercise for DFO to try to resolve.

2. Acoustic Tomography: The use of acoustic tomography had previously been heralded as a powerful remote sensing technique which would soon provide a monitoring capability of ocean conditions across wide expanses (eg. 1000s of km). Millions of research dollars have been spent on large experiments in the USA, yet it is recognized that the technique lacks a unique solution. While acoustic tomography still holds much promise it was suggested that Canadian efforts in this field should be more modest, focussed and biased towards addressing smaller components of the overall problem.

3. Herring: Several problems associated with herring and related acoustical research were identified, including: the need for multi-scatter measurements of herring, the lack of an acoustic model to describe herring, and the need to describe the herring school structure using acoustic techniques.

4. Verification: The reproducibility of results in acoustics related to biology was questioned. It is recognized that several problems preclude the possibility of measuring the "true" biological resource being investigated during site specific surveys, including fish movement relative to the vessel, multiple counting of fish, fish orientation, fish density, vessel disturbance of fish, etc. Some efforts are needed to verify that the acoustic measurements taken are indicies of the actual biological resource since the biological resource is often changing rapidly in both time and space during a survey.

5. Interpretation: It was suggested that more emphasis needed to be placed on research directed to converting acoustic data into biological data. In part the problem lies with inadequate or non-uniform equipment calibration, and in part that satisfactory ground truth observations are difficult or impossible to obtain.

6. Standard Sound Velocity: For hydrographic surveying purposes it was suggested that significant charting improvements could be accomplished if efforts could be directed to improving standard sound velocity tables. Mathews' tables are presently used. Conversely, since Mathews' tables seem to be universally applied, site specific users could easily apply their own correction factors.

7. Frequency Requirements: Often significant additional information can be obtained for secondary or tertiary users if acoustic sensors are adjusted over slightly different frequency ranges. The most obvious case in point is the competing interests of the geologist and the hydrographer; one wishes to give as much information of the bottom and underlying materials as possible while the other wants to obtain as accurate water depth as possible. Efforts should be made to optimize as much information as possible from the various acoustic sensors being used in the DFO Science program. The use of hydrographic sensors for biological research was mentioned as a possibility.

Theoretical and Experimental Foundations in Fisheries Acoustics

Robert Kieser
Pacific Biological Station
Nanaimo, B.C.

Fisheries acoustics offers a variety of tools such as the echo sounder, sonar or acoustic tags. Many applications such as fish finding can be done with inexpensive off-the-shelf instruments and require little training. This is particularly true in situations where qualitative information suffices and where "ground truth" is available. This is the case in a typical fishing application. The need for quantitative information however imposes different requirements. In this case we can optimise the available information by close attention to the theoretical and experimental fisheries acoustic foundations.

The following idealized fisheries acoustic experiment serves as an illustration. Three major components can be isolated when we set out to measure the fish population in a given area: biological factors, sampling design and the acoustic measurement.

Biological factors include the availability of the target fish in the survey area and in the water column. Fish are highly mobile and it is often difficult to establish a time when they are relatively stationary, are evenly distributed and are not near the surface or the bottom where acoustic sampling is difficult. Few general rules exist, a detailed knowledge of the biological situation is important. The situation is complicated by the fishes' reaction to the vessel that is used in the survey. These effects can be large and are difficult to quantify.

Sampling design is the second component in our idealized experiment. At any given moment the acoustic beam samples only a small fraction of the total volume of water. Over time a substantial fraction is sampled. Limitations are imposed by cost and more fundamentally by time. Longer data acquisition times increase the distance fish move. In practice we often simply assume that a representative fraction of fish has been sampled.

In contrast to these biological and sampling design factors the measurement of the fish that actually pass through the acoustic beam is much better understood. Studies have lead to an understanding of the propagation of sound in water, of transducer characteristics and of acoustic properties of single fish or aggregations of fish. This work has lead to strong physical models that allow us to relate the acoustic information to biological parameters. The echo integration model (e.g. Ehrenberg and Lytle 1972) for example relates echo energy to fish density. In many cases rigorous experiments have been performed to test these models. Experiments on caged fish (e.g. Foote 1983) for example have been used to test the echo integration model.

Acoustic theories and experiments thus provide a powerful guide for measurement of fish that pass through the acoustic beam. Not only can we measure such parameters as fish density and size accurately, we also can estimate their possible precision.

It may appear paradoxical that we have better confidence in the complex acoustic measurement than in our ability to estimate biological or sampling parameters.

This leads to three important conclusions:

1) Quantitative fisheries acoustic work must be based on a physical measurement.

2) There is a need to develop and test advanced fisheries acoustic models that provide information on parameters such as fish flux or species.

3) Given the relative reliability of estimates of fish density etc. in the acoustic beam we now can design experiments to improve our knowledge of biological factors and sampling design.

References

Ehrenberg, J.E. and D.W. Lytle. 1972. Acoustic Techniques for Estimating Fish Abundance. IEEE Trans. on Geoscience Electronics. GE-10, pp. 138-145.

Foote, K.G. 1983. Linearity of Fisheries Acoustics, With Addition Theorems. J. Acoust. Soc. Am. 73(6), pp. 1932-1940.

Components of Sonar Systems

James L. Galloway, P. Eng.
Engineering Services
Institute of Ocean Sciences
Sidney, B.C.

Introduction

Sonar systems consist of many components, some of which have unclear functions to those not working within the field. Effective communications between technologists constructing or purchasing sonar systems and scientists using these systems is essential for achieving established goals of acoustic based research programs. The conceptual design stage of a project results in commitment to a path early on in the development cycle so that it is critical for all involved to have a common technical understanding and language. Each profession has its own jargon or buzz words to help make communications more efficient and this is particularly true of engineering. In an effort to establish common ground for acoustic systems design, it can be helpful to describe a generic sonar system outlining the function of each component and the reason it is part of the sonar system.

A Generic Sonar System

A typical sonar system is depicted in the block diagram and includes most of the essential components of an underwater acoustic system. The system can be thought of as three distinct parts: transmitter, medium, and receiver. The function of the transmitter is to introduce sound energy into the water to perform some useful task. The transmitter is not always man-made, as with naturally generated sound, but is always present in some form. The medium consists of the water, whether fresh or saline, or sub-bottom and is generally non-homogeneous with dynamic acoustic characteristics. The receiver subsystem provides the desired information and can be extremely simple as in a standard sounder or complex as in a towed array processor.

The Transmitter

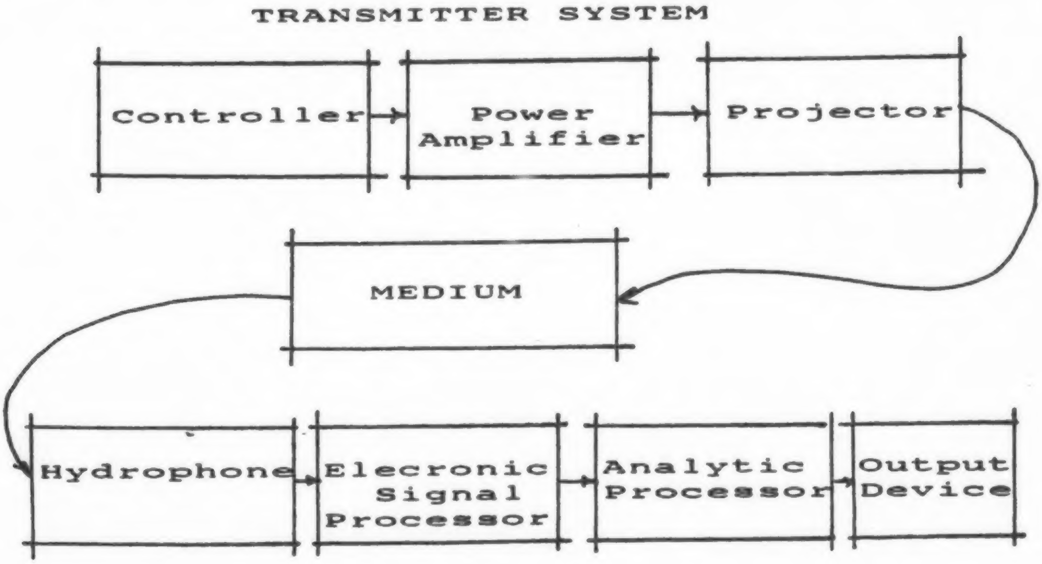
The transmitter generally consists of three components: a controller of some type, a power amplifier, and a projector. The controller is the device which initiates the generation of acoustic energy and may be a scan recorder which is part of an integrated sounder or may be an electronic timer or a software driven computer. One could think of the action of rain or waves as controlling the production of sound. Power amplifiers can be electronic, chemical, or mechanical in nature. Electronic amplifiers are either linear or non-linear with little difference to the form of the acoustic energy produced while an explosive charge is a chemical amplifier and an air gun is an example of a mechanical device. A suitable projector completes the trio and provides the mechanism to convert source energy to sound energy producing a source level in the water which is expressed in decibels (re: power/area). Conventional projectors or transducers are usually ceramic or ferrite, corresponding to exploitation of electric field or magnetic field technology.

The Medium

Sound waves travel within the medium and are subject to bending and losses in static and dynamic modes. The medium suffers from non-uniform sound speed dependence with depth, effectively resulting in modification of the direction of sound transfer.

The Receiver

The receiver subsystem contains many components, not all of which are present in a given system. Hydrophones, electronic signal processing, and some type of output device are usually present with some systems containing an analytic processor. A hydrophone is the reciprocal of a projector, converting sound energy to electrical energy. Hydrophones are also called transducers and can be made of ceramic, ferrite, mylar, or other materials. The electronic signal processing box in the block diagram includes a preamp and filter which boosts the hydrophone response and optimizes the noise characteristics of the sonar system. Other components are a type of gain equalizer to correct for known acoustic losses like spreading or dynamic losses like biological scatterers and a type of demodulator to provide amplitude or phase information. More sophisticated systems include an analytic processor to manipulate the data, usually in digital form. This processor can be applied to enhance a signal contaminated with noise, or to process using standard mathematical procedures like integration, spectral analysis, correlation, histograms, etc. Finally, an output device provides the garnered information in a form suitable for interpretation and may be on paper or video as with standard sounders, simple liquid crystal displays or neon bulbs as with inexpensive sounders, detailed graphical images of complex amplitude/phase information, and stored on mass storage media as with analog or digital magnetic tape or magnetic disc.



RECEIVER SYSTEM

TYPICAL SONAR SYSTEM

Signal Interpretation and the Use of ECOLOG in Fisheries Abundance Studies

P.R. Boudreau and L.M. Dickie
Biological Sciences Division
Bedford Institute of Oceanography

The ECOLOG dual beam acoustic detection system has been designed to offer information on average size and density of fish at the mesoscale (i.e. 10's to 100's of meters) sampling level. Its use has been directed particularly to studies of demersal ("ground") fish such as cod and haddock, where there are marked changes in the degree of aggregation and of average size and species in horizontal distances of less than 1 km. The results appear to be useful for assessment of abundance, as required routinely by DFO, and also for distinguishing between "abundance" and local availability, which affects catchability in fisheries, as well as providing scientific data on the size scaling of production processes in demersal fish populations. The data also seem to be relevant to estimation of abundance in pelagic fishes but further development of field survey methods is required.

The principle developments of the dual beam system at BIO have been in the identification of various biological or target factors which affect the measurement of acoustic target strength and permit its conversion to fish size or biomass. In particular it has been shown that while the dual beam acoustic system works in accordance with the theoretical expectations for ideal targets, fish targets impose special additional considerations in relation to species, position in the beam and aspect. Experimental observations of individual fish in both field and laboratory have led to the formulation of new algorithms which include digitization of the signals, grouping of signals, the identification of "peak" voltages within pings, tracking of individual echo levels within successive pings in the individual fish envelope, fitting of average perspective effects and identification of the average acoustic size for each individual.

Average acoustic size is essential for the estimation of volume sampled in calculating the density of targets which vary in size as much as groundfish populations do.

The algorithms have been applied to survey data taken in groundfish surveys. The results show that numbers density calculated acoustically is an unbiassed estimate of numerical abundance calculated from groundfish trawls made under good towing conditions. There is no evidence of "saturation" of acoustic density estimates at the highest catches made by the experimental fishing. Data from the surveys are also used to derive empirical relations between acoustic fish size and biological fish size for various species. Dogfish and pollock appear to have a different acoustic to biological length relation than do haddock, cod and redfish but volume scaling appears to successfully correct the density estimates for these differences.

Our somewhat antiquated prototype appears to have been successfully updated by Seastar in a technology transfer supported by the U.P. and Ocean Development Programs.

The Application of Image Analysis Techniques To The Interpretation of Acoustic Survey Data

N.A. Cochrane
Bedford Institute of Oceanography
Dartmouth, Nova Scotia

Introduction

Investigators at the Bedford Institute of Oceanography have been using multiple frequency acoustic backscatter at 12, 50, 120, and 200 kHz to quantitatively study plankton aggregations and ocean microstructure. A new deep-towed sonar being developed for DFO by Seastar Instruments Ltd. will provide 8 channels (frequencies) in the range 50 kHz to 1 MHz. The massive size and high information content of digital data sets generated by such systems creates practical problems for analysis. We have investigated image processing and display techniques in order a) to rapidly assess the quality of multichannel data, b) to efficiently compare channels and c) to select data segments for detailed quantitative analysis.

Techniques

Techniques utilized for mass data display have included:

1) Grey scale recording in real-time. Disadvantages a) the impracticality of running large numbers of chart recorders simultaneously; b) an effective dynamic range of only about 20 dB; c) the difficulty of comparing channels (separate charts) in detail; and d) noise feed-through from electric write systems into sounder front end electronics (often they must be turned off resulting in no permanent copy).

2. Post acquisition digital playback to grey scale recorders (EPC Model 1600) with or without spatial averaging. Advantage - signal dynamic ranges can be compressed and a restricted palette of grey levels can be assigned by selected algorithms. Disadvantages - a) cumbersome setup and operation (required use of two minicomputers simultaneously); b) limited grey scale range (maximum 16 levels, about 8 discernible in smaller areas); and c) channel intercomparison difficulties as above.

3. Contoured data sets. We are using this technique extensively at present. Advantage - instant precise quantitative information. Disadvantages - a) difficulty of quickly intercomparing channels; b) normally low spatial resolution due to data smoothing required to produce well behaved contours. This results in the loss of point scatters and evidence for certain system malfunctions such as brief noise bursts.

4. Image processing techniques. By image processing we mean the application of selected numerical manipulations to images stored in digital form for subsequent display to a CRT or copy device. Normally both the intensity and chroma (colour) of each discreet image element (pixel) can be controlled over a nearly continuous range of values.

Image Processing

Our exposure to image processing has risen from a VAX 750 mainframe based Perceptron image processing system installed at BIO for the processing and display of satellite imagery. The system permits 512 x 512 pixel three primary colour, intensity modulated overlays, to be displayed on a CRT for either direct photography or hard copy dump to an ink jet printer (at reduced resolution). Two modes of data presentation have been utilized: 1) Single channel pseudo-colour in which echogram intensity variations are mapped into a preselected colour palette for CRT display. 2) Multichannel false colour images in which separate frequency channels are superimposed in different intensity modulated primary colours. This produces an acoustic analogue to the Landsat multispectral scanner imagery.

We have used pseudo-colour to discern regions of intense scattering in the core of soliton-like internal waves recorded in a 1984 cruise with the Ocean Circulation Division, AOL, BIO. Potential advantages of pseudo-colour display include better delineation of detail if palette and signal processing are appropriately chosen and an improved ability to spatially correlate areas of constant image intensity. Grey scale displays of both the chart recorder and CRT type typically have poor amplitude separation near the limits of their reproduction ranges.

Multichannel false colour imagery has the unique advantage of allowing detailed comparison of two or more channels in direct visual superposition. Such imagery is only effective for spatially separating discreet biological populations if the populations possess differing frequency responses for the channels examined.

This technique was used in the analysis of deep accustic sounder data collected in Emerald Basin in 1984 (Cochrane and Sameoto, 1987). Here echograms were superimposed after 20 log R + 2*R time variable gain corrections, 50 kHz in red and 200 kHz in blue. Clear delineation was obtained of near-Raleigh regime (steeply rising target strength with increasing acoustic frequency) small copepod scatters (mature Calanus species) below 150 m from larger geometric scatterers (slowly changing target strength with frequency) in the upper 100 m. Additional image enhancement was also obtained by pixel by pixel subtraction of a system + ambient noise power estimate obtained during suppressed transmit.

Several difficulties attend exploitation of false colour imagery: a) Use of 3 colours (channels) rather than 2 tends to be visually confusing. Part of the problem stems from our rather poor hard copy reproduction system. b) Sounder TVGs must be accurate unless inter channel differences are large. In practice this requires channels be carefully selected and digital data preprocessed to improve TVG accuracy before display. Absorption losses are highly ambient temperature dependent. c) Delineation of resolved point scatters requires a 40 log R spreading time variable gain correction rather than the 20 log R appropriate for unresolved diffuse scatterers. Proper superposition of multiple channel point scatterer images requires the acoustic transducers be mounted in close physical proximity, have matched beam patterns, and transmit equal pulse lengths. For diffuse scattering regions (common with plankton) these requirements can be somewhat relaxed. d) Normally pre-processing is required to reduce image contrast for easily viewed CRT displays (as is also the case for satellite imagery). A fourth-root amplitude mapping was used for the two frequency Emerald Basin applications. e) Systems permitting independent modulation of primary colour intensities necessary for false colour imagery tend to be expensive, time consuming to utilize, and not well adapted to field applications.

Conclusions

Image processing, especially multichannel false colour displays which allow channels to be compared in superposition, has tangible advantages in rapid perusal of large acoustic data bases. However these techniques are not magical. Usefulness requires familiarity with the biology, critical knowledge of equipment performance, appropriate selection of display channels, and careful adjustment of image parameters for maximum discrimination.

Our experience suggests that carefully chosen real-time displays could enhance the effectiveness of direct biological sampling and related studies in a field environment. It is planned to implement a PC based colour display on the new Seastar Sonar. This will center about a PC work station equipped with a PGA card capable of 640 x 480 resolution using a palette of 256 colours and working in conjunction with an HP ink jet printer for permanent record. Such a unit will allow pseudo-colour and perhaps very restricted types of multichannel display with appropriate palette mappings.

Ultimately the most challenging application of these imagery techniques may be for high capacity displays of processed and reduced data. For example, if one were to first apply inverse modelling algorithms to convert a multichannel zooplankton backscattering data set to dominant species size and number density (the main thrust of our current research efforts), followed by a mapping of size to image chroma and number density to image intensity within the format of a time x depth sonar section, very useful and interpretable displays for the marine biologist might be obtained.

Reference

Cochrane, N.A. and D.D. Sameoto. 1987. Multichannel False Colour Echograms as a Biological Interpretive Tool. In: Progress in Underwater Acoustics ed. H.W. Merklinger. Plenum Press, New York, pp. 129-135.

Geological Interpretation of Sidescan Sonar, Subbottom Profiler and Swath Sounding Data

D. Russell Parrott and Gordon B.J. Fader
Atlantic Geoscience Centre
Geological Survey of Canada

Acoustic techniques are used extensively by marine geologists and geophysicists to obtain information on the nature and distribution of seafloor and subsurface sediments. During geophysical surveys undertaken by the Atlantic Geoscience Centre of the Geological Survey of Canada, a suite of acoustic survey techniques are generally employed for purposes of mapping the thickness and distribution of sediments and features at the seafloor. A typical survey will collect echo sounder, sidescan sonar, subbottom profiler, and shallow seismic reflection data. Bottom photographs and samples are later collected to provide groundtruth for interpretations of the acoustic data. The major objective of the surficial geology studies is the mapping of the type, character, and distribution of sediments and bedrock.

Many of the survey tools used in geological mapping programs, such as echo sounders, sidescan sonar and swath survey techniques, are also used by hydrographers for bathymetry profiling. The objectives of hydrographic and geological mapping are quite different and therefore the information extracted from the data, and the interpretation techniques also vary.

Sidescan sonar data provides the geologist with information on the texture or sediment type and the morphology from both sides of the survey vessels track. Changes in the acoustic reflectivity and surface roughness of sediments give rise to changes in the character of the acoustic pulses reflected from the seafloor. When these echoes are displayed on a graphic recorder information can be extracted about sediment type and morphology. Sidescan sonar systems with ranges from a few metres to about 30km have been used in the mapping programs, with both medium and short range systems often towed concurrently. Much of the sidescan sonar interpretation performed at present uses the qualitative aspects of the sonar data as displayed on the graphic record to provide information on the morphology, distribution and texture of the sediments. This information is interpreted to understand processes such as iceberg scouring and pitting, gas venting and faulting. Work is currently underway in a number of centres to make quantitative estimates of across-track seafloor roughness for use in automated sediment classification schemes.

Geologists use bathymetric data collected with echo sounders to study the shape of large scale features such as sand ridges and small scale features such as ripples. Information on the acoustic reflectivity of the sediment is also present in the sounder data and (if the sounder gains are set properly) information on the acoustic character and type of sediment can be obtained when acoustic energy penetrates the sediment. High resolution subbottom profiler data, such as that provided by the Huntec Deep Towed Seismic (DTS) system, are used to supplement the information present in sounder data and enable the study of surface and subsurface topography, and the nature and thickness of surficial sediments. The gain levels in the system are generally adjusted such that the sediments with high acoustic reflectivity, such as sands and gravels, appear on the graphic record at a much higher grey level than do the softer sediments such as clays and silts. Areas with a smooth seafloor generally show as a well defined reflection, while areas with high surface roughness show as a much more diffuse, broader reflection. Many of these factors can be inferred directly from the graphic record, however, continuing research is being undertaken to allow a direct quantitative estimate of acoustic reflectivity, surface roughness, and the effects of the attentuation of sound by different sediments. At present the acoustic reflectivity of the seafloor is calculated and displayed on the graphic record, along with the seismic section. This has proven to be a valuable interpretation aid, and provides a lithologic component to the seismic stratigraphy.

Swath survey techniques have only recently become available for use by geologists. They are primarily used for reconnaissance work where detailed bathymetry is required before survey by deep towed vehicles or submersibles. The higher spatial resolution of these systems is valuable for mapping the detailed bathymetry of an area, however, at present the systems provide little or no information on the acoustic reflectivity or scattering characteristics of the seafloor. Changes are required in the method of data logging and presentation to allow the data to be displayed as a grey scale record (along with the bathymetry data), and for signal processing to calculate reflectivity and scattering. For the present, sidescan sonar data collected during the swath survey would provide some of the required information.

Acoustic techniques offer a rapid, economical, non-intrusive method of obtaining information about the stratigraphy and properties of the seafloor sediments. During the past decade there has been a dramatic increase in the level of sophistication of the equipment available for seabed and subsurface surveys, and in the signal processing techniques applied to the data collected with these systems. Processing of the data allows quantitative measures of the acoustic reflectivity, attenuation, and scattering parameters of the seafloor sediments. Graphic recordings emphasize the coherent portion of the reflected energy and allow a qualitative estimate of sediment stratigraphy and characteristics. Through signal processing techniques, information can be extracted from the coherent and incoherent components of the data for estimation of surface character and sediment properties. These calculated parameters can be applied through interpolation between areas of available groundtruth. Acoustic techniques are used extensively to establish the regional geological framework and can be used to extrapolate available ground truth into previously unsampled areas, and to optimize the design of a sampling program to provide the necessary ground truth for the survey area.

Interactive Visual Editing of Hydroacoustic Data from Fisheries Surveys

D.S. Miller and C.R. Stevens
DFO, Science Branch
St. John's, Newfoundland

Acoustic data collected during surveys of fish stocks typically is contaminated from a variety of different sources. Consequently, analysis of the data to provide a biomass estimate is complicated by the need to account for extraneous sources of noise that can bias the estimate of fish biomass that one is attempting to derive. An interactive visual acoustic editing system has been developed for DFO Science Branch, Newfoundland which provides a versatile and easy method to address this problem.

Stock abundance estimates from acoustic data are derived by one of two basic methods, echo-integration, or echo-counting. Echo-counting can be used when individual targets can be discriminated in the acoustic data and an estimate of fish density can be calculated if one knows the volume of insonification of the acoustic sample. More typically, one encounters multiple targets which cannot be discriminated individually and one must use echo-integration to derive an estimate of fish density. In either case, if the acoustic data contain samples from other than valid echo returns of the target species, these must be removed or the estimate of density that is calculated will be positively biased.

Typical sources of contamination are electronic noise, acoustic noise such as ship propellors, turbulence in the near surface layer, sampling of the bottom before bottom detection occurs and sampling is curtailed, echo returns from non-target species, bottom shadowing, and interference from marine mammals such as whales and porpoises. All of these have occurred at some point during biomass surveys conducted by our laboratory and have complicated the task of deriving reliable biomass estimates.

In the Newfoundland region, hydroacoustics was first used to derive estimates of capelin abundance in NAFO divisions 2J3KLNO. Because capelin is a densely schooling species, echo integration is the only method that can be used. At present, hydroacoustics is also used to derive estimates of cod and redfish abundance and echo integration is used as the primary analysis method. Software to perform echo integration was extensively modified to allow some data editing capability such as surface and bottom sampling offsets, deletion of samples contiguous to bottom, specification of a time window to omit samples, and variable sample thresholds. As implemented, these were still relatively crude editing tools and still required viewing of the paper echogram to decide which editing features to invoke. Monochrome paper echograms are useful to a certain degree but are limited in their capability to display a wide dynamic range of echo intensities.

With the increasing availability in recent years of high resolution colour displays, it has become feasible to display the collected digital acoustic data in colour so that the problem of determining echo intensity from a visual monochrome display is overcome. At the same time, it is possible to define specific areas in the displayed echogram for data deletion using a device such as a light pen or mouse.

An interactive system for editing fisheries hydroacoustic survey data should have the following capabilities:

1. Bottom removal algorithms which will allow data contiguous to bottom or in the near bottom zone to be removed.

2. A mechanism to define encircled areas on the displayed echogram where data should be eliminated if it is considered to be noise or non-target species echo data.

3. A mechanism to define vertical windows to the surface or to bottom where data is to be eliminated.

4. A user definable colour scheme to represent echo intensity.

5. The echograms should be able to be referenced to the surface (i.e. the transducer face) or to the bottom.

6. Specification of an optional offset depth at which data display will begin.

7. The option to display one ping or a function of N pings for each display pixel column.

8. The ability to move backwards in a data sequence.

9. A rapid and simple communications package to move data between a separate computing system and the data editing system.

10. The entire editing system should be compact and rugged enough so that it can be used onboard a research vessel as data is being collected or in the laboratory for further editing of data upon completion of a survey.

In 1985, an unsolicited proposal was presented by FEMTO Electronics to DSS and was accepted. An initial version of the system was completed in late 1987 and after minor modifications is now being used in the hydroacoustic survey program in the Science Branch, DFO, Newfoundland.

The hardware for the hydroacoustic data editing system consists of an IBM PC/AT compatible computer with the following components:

1. Professional Graphics Adapter (PGA)
2. High speed matho co-processor
3. 90 megabyte high speed hard disk
4. Graphics tablet and pen
5. Serial (RS232) and parallel (IEEE 488) communications links

The hardware specified above combined with the custom software developed by FEMTO Electronics has given us a useful and versatile editing tool that meets all the specifications previously mentioned.

Overview on Aspects of Signal Interpretation

Chairman: D.L. McKeown
Bedford Institute of Oceanography
Dartmouth, N.S.

This session was designed to address the methodologies used by department scientists to extract meaningful information from their acoustic measurements. Signal processing is normally deemed to refer to a set of discrete and specific steps such as deconvolution, integration and so on that a signal undergoes before it is examined for information content. These might be implemented in hardware or software. On the other hand, interpretation tends to have a much broader meaning in the sense that it refers to the entire process of translating the acoustic signal into end user information. One example of such an interpretation procedure would be the conversion of received backscatter amplitude to a measurement of biomass. Thus, the qualifier "interpretation" rather than "processing" was deliberately chosen to emphasis the theme of this session.

The following papers addressed that theme:

Theoretical and Experimental Foundations in Fisheries Acoustics

Robert Keiser
Pacific Biological Station
Nanaimo, B.C.

This paper provided an overview from the perspective of a physicist as to the physical validity of various fisheries acoustic measurements being made using echo sounders, sonar and fish tags. As an example of how important it is to understand the measurement process in both the physical and biological context, he described an experiment done to determine the biomass that exists in a particular lake. Both the weir count and acoustic echo integration yielded counts of about 200,000 fish whereas acoustic echo counting showed only 110,000 fish present. He then rationalized this discrepancy by examining both the acoustic parameters which prevailed during the experiment and the biological properties of the target. In conclusion, he stated that fisheries acoustics measurements must have a sound physical foundation and proper care must be taken over calibration so that measurements can be correctly quantified. He also emphasized the need for advanced fisheries acoustic models.

Components of Sonar Systems

James Galloway
Institute of Ocean Sciences
Sidney, B.C.

The author reviewed the physical building blocks of a sonar system including the classical signal processing hardware such as filters and software such as spectrum analysis. This set the scene for subsequent discussions of particular sonar system implementations.

Signal Interpretation and the Use of ECOLOG in Fisheries Abundance Studies

Paul Boudreau and Lloyd Dickie
Bedford Institute of Oceanography
Dartmouth, N.S.

This presentation described how ECOLOG was developed to address particular fisheries problems, namely, estimates of stock abundance and fish size. The authors identified the various factors which affect the "acoustic" size of fish and how they were dealt with by the signal interpretation procedures within ECOLOG. Using their system, they have observed good correlation between acoustic estimates of stock abundance and groundfish trawls. Acoustic model development for similar assessment of pelagic species is still required.

The formal presentation was followed by a lively discussion concerning the validity of their interpretation procedure. Subjects raised included their methodology for discriminating between overlapping echoes from different fish and their empirical method of accounting for variations in target strength as the fish changes its orientation within the acoustic beam. The general conclusion seemed to be that the hardware was adequate to the task but that the acoustic model for demersal species needed further refinement.

The Application of Image Analysis Techniques to the Interpretation of Acoustic Survey Data

Norman Cochrane
Bedford Institute of Oceanography
Dartmouth, N.S.

He presented one approach to the problem of interpreting large quantities of multi-spectral acoustic data. His sonar system generates 20 MB of data in 15 minutes during multi-frequency insonification of zooplankton communities and physical oceanographic features in the water column. For real-time data monitoring during the experiment he relies on a limited dynamic range grey-scale recording using one recorder per channel. During post-processing of the recorded data, improved grey scale records are obtained by compressing the dynamic range. He can also produce contour plots of reflected energy in each channel to provide an overview but this leads to a loss of spatial resolution.

Using a PERCEPTRON image analysis system he has been able to improve the information content of his sonargrams through a process he refers to as pseudo-colour. In this procedure, the reflected acoustic signal intensity variations at single frequency modulate a palate of colours. This appears to add dynamic range to classic grey-scale echograms and thus enhance detail. He also has developed a false-colour display mode wherein the reflected signal intensity at each frequency modulates the intensity of a different primary colour. These are then overlayed on a single display screen for viewing. This has permitted a detailed comparison of the acoustic response of various targets to different frequencies. He concluded his talk with a projection of where this approach to multi-spectral acoustic signal display might lead.

Geological Interpretation of Sidescan Sonar Sub-bottom Profiler and Swath Sounding Data

Russell Parrot and Gordon Fader
Atlantic Geoscience Centre
Dartmouth, N.S.

The authors provided an insight into the methodologies geologists are using to interpret acoustic records in order to produce surficial geology maps and to delineate sea floor features which might pose problems for man-made structures. Changes in acoustic reflectivity and surface and volume scattering of sediments produce responses which can be used to map their distribution in 3 dimensions. They are using swath systems to map detailed bathymetry but present system implementations provide no reflectivity or scattering information thus they are not being used for geological mapping. They have tended to lead DFO scientists in the introduction of new acoustic technology. For example, for some years they have been routinely carrying out high resolution sub-bottom surveys using a real-time signal processing device which displays a measure of acoustic reflectivity on the echogram along with the grey-scale seismic record. This system has proven useful in the detection and delineation of features such as shell beds on the continental shelf.

Interactive Visual Editing of Hydroacoustic Data from Fisheries Surveys

Dan Miller and Chris Cooper
St. John's, Nfld.

They presented a method of interactive graphical editing of large acoustic data sets on a microcomputer to eliminate noise (i.e. anything other than the target species) which might bias biomass estimates. The system software was designed to be very modular so that it could be adapted to other applications and care was taken to make the system both simple to operate and very responsive to operator commands. The high resolution video display is designed to mimic an echogram. Using a mouse, light pen or graphics tablet, areas of the acoustic record or individual pings can be selected for editing via various procedures. A hardware implementation of the system was demonstrated and aroused considerable interest. A number of researchers present at the workshop seemed to recognize that it could have application to their work.

The above, as well as other presentations made during the workshop, lead the session chairman to the following overall observations:

1) Acoustic models which are intended to explain the experimental observations lag the level attained by the hardware being employed to make the measurement. Improved models which will benefit physical, biological and fisheries researchers are needed and more resources are required in order to address this problem.

2) Modern Digital Signal Processing (DSP) chips will permit the physical implementation of complex algorithms in real-time hardware with a high degree of reliability. Potential uses include the extraction of phase information from signals and the implementation of spread spectrum processing.

3) DFO should begin planning next generation acoustic systems which would utilize technologies such as spread spectrum and Doppler measurements.

4) There is a growing understanding amongst end users of the need to properly quantify their acoustic measurements in addition to ground-truthing them. Consequently, there is a need within DFO to develop acoustic calibration facilities which are particularly suited to our special requirements and which are readily available to end-user scientists.

5) Some centres of research within the department such as the Pacific Biological Station and the Fresh Water Institute appear to lack adequate access to supporting resources such as electronic and mechanical engineering design while others such as IOS and BIO seem more adequately served. Perhaps some method of providing access by researchers at the former establishments to existing resources at the latter should be explored.

6) While not actually mentioned during the workshop, the use of interpretative computer languages such as LISP and PROLOG rather than the declarative ones such as PLASCAL and FORTRAN will probably have a significant effect on the implementation of signal interpretation procedures.

7) A broader perspective of acoustic research and development within DFO would have been gained if private sector organizations doing research for DFO were invited to make presentation at the workshop. For example, Seastar might have been invited to present details of their plans to commercialize ECOLOG and the systems engineering philosophy they are applying to the design of the multi-frequency sonar system for BIO.

CSS 'FCG SMITH'
HYDROGRAPHIC ACOUSTIC SWEEP VESSEL*

Adam J. Kerr, Alan L. Adams and Robert G. Burke
Bedford Institute of Oceanography
Dartmouth, Nova Scotia

THE SHIP

Principal Particulars

Length overall	34.8m
Length waterline	32.8m
Breadth overall	14.0m
Breadth - single hull	4.0m
Depth - moulded	3.4m
Draft (design)	1.9m
Displacement	328 tonnes
Trial speed	12 knots
Shaft horsepower @ 1800 rpm	2 X 400 HP
Crew	10
Classification	Lloyds + 100 A1 East coast of Canada Home Trade II.

Machinery

Main propulsion	2 Badouin 6P 15 SRC M propulsion systems with CP propellers and fixed nozzles.
Auxiliary power	2 Caterpillar 3306T auxiliary engines with MSC 334C Stamford generator to produce 270 kW of electric power.

---

* Reprinted from International Hydrographic Review, Monaco, LXIV (2), July 1987

Electronic Equipment

Radars	2 Decca Gyro stabilized RM1290A X band radars.
Echo sounders	2 ELAC LAZ 72 50 kHz depth sounders.
Navigation	2 Racal 1028 Loran-C receivers. 2 Robertson SKR 82 gyro compasses.
Communications	2 Spillsbury FMX95 FM marine radios. 2 Daniels DE1400 SSB radios. 1 Collins 251 aircraft radio. Vilks integrated telephone and internal communications unit.
Miscellaneous	Taiyo TF733 weather facsimile receiver. Ginge-Kerr Fire Scope fire detection and control system.

The FCG Smith (Figure 1) is named after Frank Clifford Goulding SMITH, who served as Dominion Hydrographer of the Canadian Hydrographic Service from 1952 to 1957. The vessel is designed for the acoustic sweeping of harbours and fairways on the Atlantic coast of Canada.

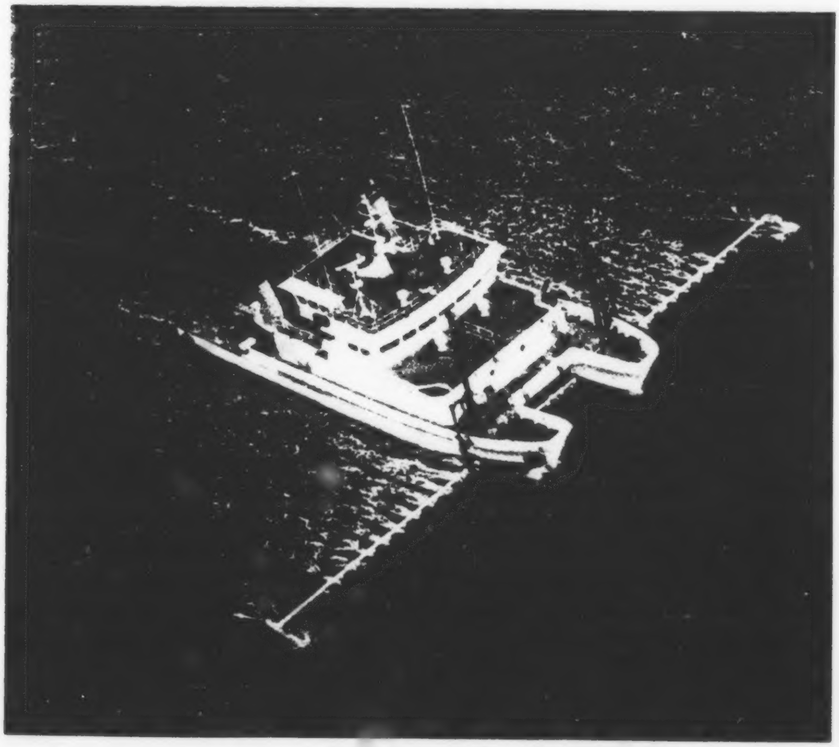


Figure 1 - The FCG SMITH

The designers for the vessel were Evans, Yeatman and Endal (Associates) Limited of Dartmouth, Nova Scotia. After due consideration of the statement of requirements, they proposed a catamaran design in order to provide the high degree of stability required for the acoustic sweep gear. They were also asked to keep the draft minimal (less than 2 metres) and to provide good manoeuvrability in order to work in the confined areas of harbours and fairways.

Navitronic Limited of Denmark was selected to provide the acoustic sweep system and electronics. The mechanical boom system for deploying the transducers was designed and fabricated by Canadian Dredge and Dock Co. Ltd., Toronto. The vessel is also designed to carry a paravane sweeping system.

FCG Smith was constructed by Georgetown Shipyard, Prince Edward Island, and commissioned on April 25, 1986. Since that time the vessel has gone into active service and is engaged in surveying channels into ports on the southwestern side of the Gulf of St. Lawrence. Apart from initial software and hydraulic problems the program is going ahead successfully.

Prior to letting the design contract, the Canadian Hydrographic Service had studied equipment available for acoustic sweeping. Several systems, both in Europe and North America, were observed in action. An independent study recommended the Navitronic equipment. Initially a portable system had been designed for the mechanical portion in order that it could be transported to, and deployed in the Arctic. In developing a system for the ship, a key issue was whether to deploy the transducers from submerged hydrofoil booms or from booms above the water surface with the transducers projecting downwards on spring-loaded "break-away" struts. The former system is used extensively in Finland and the Federal Republic of Germany. It was decided that, in view of the difficulty and cost of making repairs to submerged booms, the booms should be above water. They would be hinged at the ship end and supported by floats near their outboard extremities. The entire apparatus would be suspended from Samson posts on each side of the ship. A hydraulic control console for the booms is located on each wing of the wheelhouse. When housed, the booms and transducers are stowed along each side of the accommodations.

The catamaran design was selected to provide low roll angles and a large working area. The asymmetric hulls are connected by heavy bow girders. The machinery and fuel are carried in the hulls and all accommodation and laboratory space is above deck. The crew accommodation is small but of good quality. A computer room, occupying 18 square metres, is located on the main deck and the 33.1 square metre main plotting room is directly abaft the wheelhouse. There is a very large working deck on the after end with a 1,250 kg articulated crane on each side. Figure 2 shows the general arrangements of the vessel.

The wheelhouse is equipped with steering and engine control consoles on each wing and in the centre. To provide the high precision steering necessary the Danish EMRI system has been installed. This is interconnected with the positioning control for automatic steering along survey lines. The ship does not have total dynamic positioning.

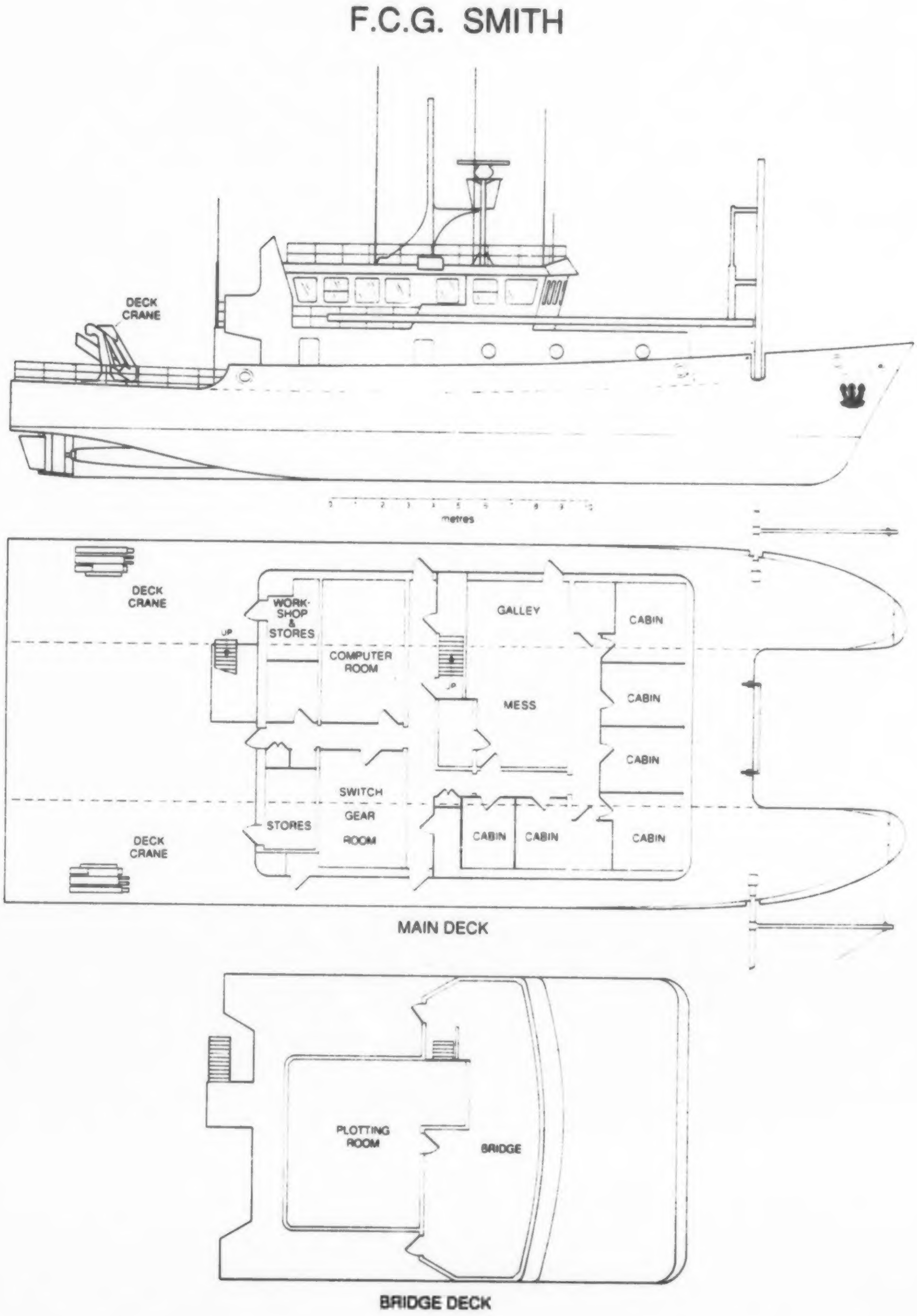

F.C.G. SMITH
DECK CRANE
metres
DECK CRANE
WORK-SHOP & STORES
UP
COMPUTER ROOM
GALLEY
UP
MESS
CABIN
CABIN
CABIN
SWITCH GEAR ROOM
STORES
CABIN
CABIN
CABIN
DECK CRANE
MAIN DECK
PLOTTING ROOM
BRIDGE
BRIDGE DECK

Figure 2 - General Arrangement Diagram

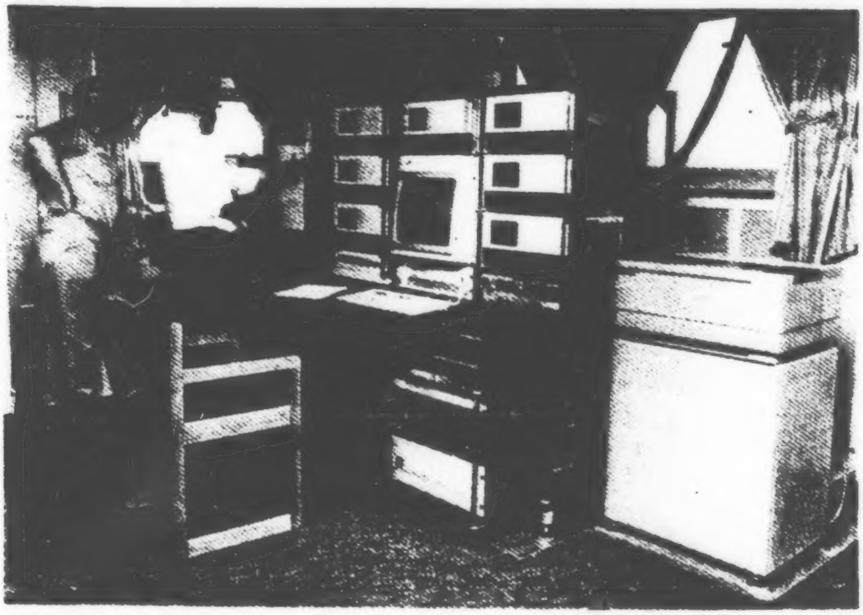


Figure 3 - Navitronic Sweep System Console

Hydrographic Survey Equipment Sweep System

A Navitronic Seadig 201 acoustic sweep system is installed on the vessel (Figure 3). A block diagram of the configuration is shown in Figure 4. The vessel is currently utilizing 29 transducers giving a swath coverage of approximately 38 metres. With the installation of another six transducers for the 1987 field season, the coverage will be increased to 46 metres. When operated in its fastest mode, the vessel is capable of making 42,000 depth measurements per minute. On a typical day up to 500,000 depth measurements are recorded on magnetic tape for subsequent off-line processing.

Two systems are being used for positioning, Motorola Mini-Ranger III and Krupp Atlas Polarfix. They may be used individually or together; however, in the latter instance all data are recorded but an integrated position is not computed in real time. Real time along-track profiles (Figure 5) of the raw depth data are generated on a Raytheon 1807 Line Scan Recorder. This record serves as a monitor on the quality of the depth data and is utilized in the subsequent post-processing procedures.

The Navitronic system is directly interfaced to the EMRI steering system. Experience to date indicates that the system is capable of consistently maintaining the ship within a few metres of a predetermined survey line so long as the ambient conditions are consistent, i.e. no heavy gusts of wind, rapid fluctuations in currents or 'spikes' in the positioning data.

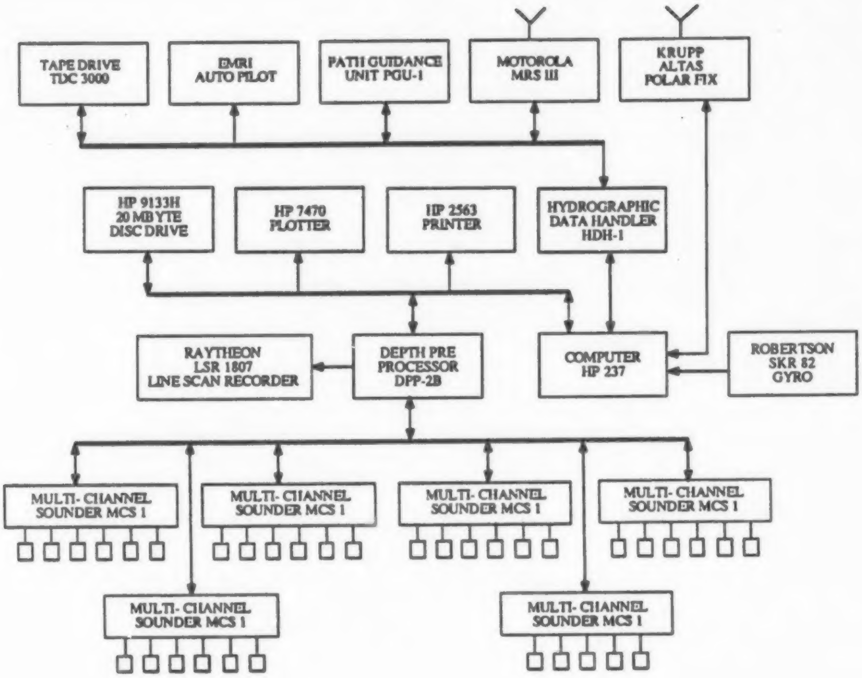

TAPE DRIVE
TDC 3000
EMRI
AUTO PILOT
PATH GUIDANCE
UNIT PGU-1
MOTOROLA
MRS III
KRUPP
ALTAS
POLAR FIX
HP 9133H
20 MBYTE
DISC DRIVE
HP 7470
PLOTTER
HP 2563
PRINTER
HYDROGRAPHIC
DATA HANDLER
HDH-1
RAYTHEON
LSR 1807
LINE SCAN RECORDER
DEPTH PRE
PROCESSOR
DPP-2B
COMPUTER
HP 237
ROBERTSON
SKR 82
GYRO
MULTI- CHANNEL
SOUNDER MCS 1
MULTI- CHANNEL
SOUNDER MCS 1
MULTI- CHANNEL
SOUNDER MCS 1
MULTI- CHANNEL
SOUNDER MCS 1
MULTI- CHANNEL
SOUNDER MCS 1
MULTI- CHANNEL
SOUNDER MCS 1

Figure 4 - Block Diagram of the Navitronic Acoustic Sweep System

All survey data are logged on a Tandberg TDC 3000 cartridge tape recorder for subsequent off-line data processing on a Micro Vax II computer system (Figure 6). The processing package for this application was designed and written by hydrographic staff at the Bedford Institute of Oceanography.

A suite of programs is available to merge, sort, carry out overplot removal and flag selected depths for plotting. The large volume of data that can be collected in any day makes data processing a formidable task. Typically, only 0.5% to 0.8% of all logged soundings are selected and plotted on the final field sheet. While the Micro Vax II is capable of keeping up with the task, two major bottlenecks have been experienced. One is in the area of generating bottom coverage plots from the depth data. This problem is due to the limitation in plotting speed of the HP 7586 plotter and can be minimized by the acquisition of a laser or electrostatic plotter. The second bottleneck lies in the area of data verification and editing. This problem has its origins in the enormous volume of data that is collected by the system and its resolution is not straightforward.

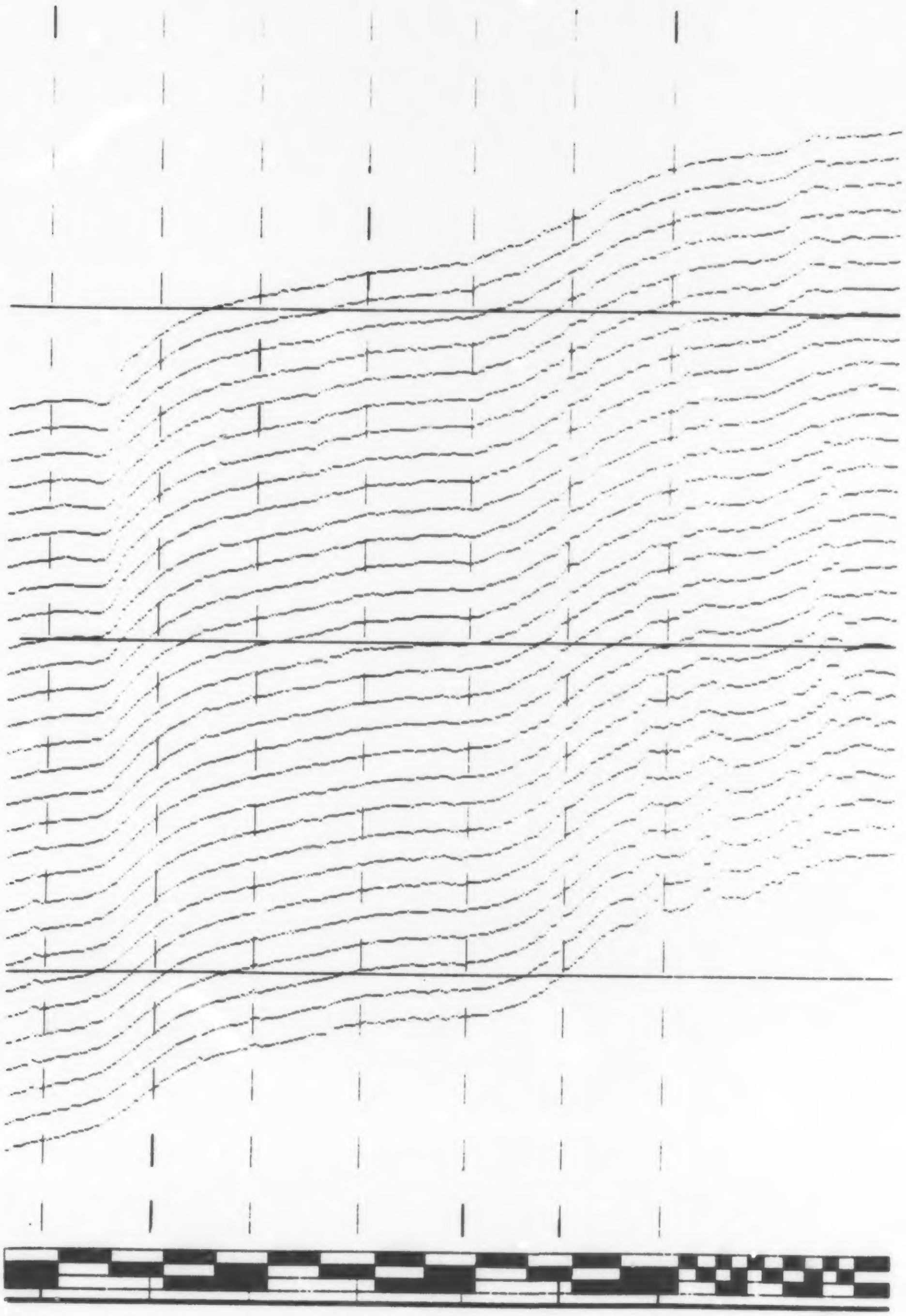


Figure 5 - Along Track Depth Profiles

Towed Paravane System

Installation of the Navitronic sweep system was given top priority for the 1986 survey season. Components for a towed paravane array similar to the system formerly employed by the Danish Hydrographic Service have been acquired and will be installed for the 1987 season.

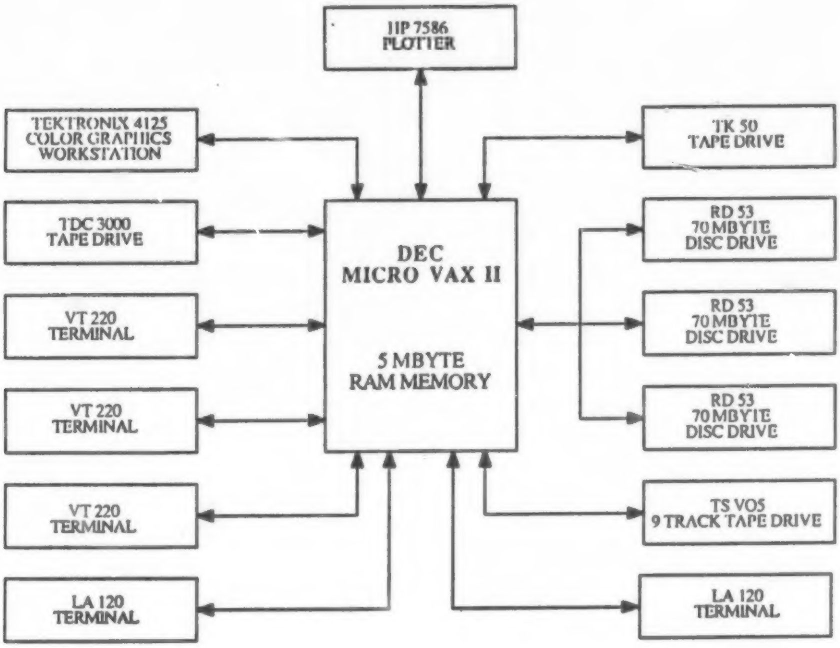

HP 7586
PLOTTER
TEKTRONIX 4125
COLOR GRAPHICS
WORKSTATION
TK 50
TAPE DRIVE
TDC 3000
TAPE DRIVE
DEC
MICRO VAX II
5 MBYTE
RAM MEMORY
RD 53
70 MBYTE
DISC DRIVE
RD 53
70 MBYTE
DISC DRIVE
RD 53
70 MBYTE
DISC DRIVE
VT 220
TERMINAL
VT 220
TERMINAL
VT 220
TERMINAL
TS V05
9 TRACK TAPE DRIVE
LA 120
TERMINAL
LA 120
TERMINAL

Figure 6 - Block Diagram of the Data Processing System

With a depth range capability of 1,500 metres, this system will complement the Navitronic Seadig 201 sweep package and be primarily used on coastal projects where the depth range of the Navitronic system is exceeded.

The towed paravane array system will consist of three transducers, one installed on the ship and two on towed floats giving a 200-metre swath. While 100% bottom coverage will not be generated, the amount of line running for a given project will be significantly reduced. ELAC LAZ 721 sounders and STG 721 depth digitizers have been acquired for this application. The equipment will be interfaced to the Navitronic system for data logging and navigation.

Summary

The FCG Smith, in the first year of operation, has proven to be a highly manoeuvrable vessel well suited to the task of providing 100% bottom coverage surveys in critical areas such as dredged channels, harbour entrances and docksites. With the implementation of a towed paravane system for the 1987 field season, the vessel will commence coastal survey projects. The vessel has been well accepted by the hydrographic staff and provides them with a new and effective 'tool' for charting Canada's navigable waters.

Noise in Acoustic Systems

James R. Parks
Institute of Ocean Sciences
Sidney, B.C.

Introduction

Noise, in the broadest sense, can be described as any process that interferes with or degrades the integrity of a desired signal. In the use of acoustical signals in the ocean environment a myriad of possible noise mechanisms must be considered which include not only perfections in acoustical/electrical interfaces but also basic limitations due to the physiology of the ocean environment itself. This paper will hopefully make a newcomer to the field of underwater acoustics aware of many of these noise sources.

The dB (Decibel) the Measure of Acoustic Power

The first topic I will cover is the basic units of acoustical measurement. Acoustic power, or energy per unit time, is typically measured using a logarithmic scale - the dB. For engineers, the dB is used to measure relative powers in both the electrical and mechanical realms as it offers the convenience of compression and simplicity when dealing with multiplicative linear systems which many closely approximate.

Specifically a dB is defined as:

$$P(\mathrm{dB}) = 10\log(P/P_{ref})$$

There P is the measured power level, and P_{ref} is a defined reference power level.

In underwater acoustics, power or intensity is measured in watts per square meter and is equal to:

$I = P^2/Zo$ where P is the average RMS pressure in Pascals ($\mathrm{Nt/m^2}$) and Zo is the acoustical impedance of the medium in $\mathrm{Kg/m^2sec}$ or rayls.

The value of Zo for water is typically 1.5×10^6 rayls.

When converting to dBs, the reference level used is 1μPa (1×10^{-6} Pa) so that the level in dB becomes:

$$I\ [\mathrm{dB\ re\ 1\mu Pa}) = 20\log[P/1\times10^{-6}]$$

This corresponds to a reference intensity of:

$$Io = (1\times10^{-6})^2/Zo = 6.49\times10^{-19}\ \mathrm{watts/m^2}$$

Numerical values are thus identical in dB for pressure and intensity.

For specifying noise, which typically has a strong frequency dependency, levels are expressed per unit bandwidth, and are called Noise Spectral Densities. Total noise may then be calculated from a power summation, specifically:

$$I \text{ (for interval } \delta f) = \int_{\delta f} p^2(f)df/Zo$$

where P is pressure in Pa.

Usually, over a limited frequency range and to a close enough approximation, the above may be calculated from:

$I(\delta f,dB)=P(dB) + 10\log(\delta f)$ which assumes a constant spectral density in the bandwidth (δf) of interest.

The Ocean Environment and Ambient Noise

Ambient noise is generally defined as "that noise that cannot be ascribed to anything in particular", however I have broadened this definition somewhat to include definitive sources of noise, both natural and manmade that are essentially uncontrollable. Ambient noise is also highly variable depending on many factors including frequency - where in the audio spectrum one is required to operate; time - time of day, time of year; location - proximity to harbours, shallow/deep water, under ice; and even dependency upon the direction in which one is listening.

Wind and Waves

At very low frequencies (<1 Hz) there are the effects of direct hydrostatic pressure of passing waves, tidal effects and seismic disturbances. In the region of 500 Hz to 25 KHz there is a strong correlation between sea state (a function of wind force) and deep ocean ambient noise known as the Knudsen spectra. Mechanisms for this noise source are breaking waves (white caps), cavitation or collapse of air bubbles near the surface and several other possible factors. Since this noise is surface generated it has a vertical directivity factor. In summary, this source is an important one that covers much of the utilized audio spectrum.

Shipping

"Distant" shipping is a principal source of ambient noise in the 5 to 500 Hz spectrum and is obviously very dependent on location. A characteristic of this source of noise which is notable is the great distances which this energy is able to propagate. This is largely due to the relatively low absorption of sound by water in this frequency band and also due to "trapping" of sound in horizontal layers of water which provides a low loss path for acoustic energy. This characteristic produces a relatively strong horizontal directionality to this source of approximately 10 dB. Fortunately this band of acoustical noise lies in a spectrum area that is impractical to use for many applications, especially much of the active acoustical work which requires the use of efficient acoustical transmitters.

Rain

Rain is a strong, although intermittent, source of noise over a broad spectrum ranging from about 500 Hz to above 20 KHz. Below 500 Hz the noise due to rain will have a tendency to be masked by other sources already mentioned. The noise level as one would expect is strongly dependent on the rate of rainfall, with a heavy downpour creating up to a 30 dB increase in ambient levels at 10 KHz. This source is also nonisotropic with a vertical directivity.

Biological Sources

Biological sources such as snapping shrimp (generally found in tropical waters), whales, and porpoises can be a strong intermittent source of sound. The mammals are generally limited to frequencies below 1 KHz but the shrimp produce an impulsive type of sound with a broad frequency spectrum of 500 - 20 KHz.

Noise Under Ice

Ice poses an interesting and increasingly important factor in the acoustical environment with the ever increasing interest in the Arctic. Under a continuous ice cover the variance in noise level can be quite dramatic when, under a rising temperature, the ambient noise level is depressed well below sea state 0 levels, to an impulsive type of noise some 40 dB higher when the ice is forming stress cracks under falling temperatures. A broken ice field too has a different noise characteristic due to continual motion and wind interaction.

Thermal Noise

The final ambient noise source I will mention is thermal noise which is highly predictable (theoretically and practically) and is due to the thermal energy of water molecules. The noise spectrum level is:

$$NL = -15 + 20\log(f) \quad (\text{dB re } 1\ \text{uPa})$$

where f is in KHz. As can be seen it has a spectrum level that rises at 20 dB per decade and imposes a lower threshold on the sensitivity of any hydrophone.

Reverberation and Multipath Effects

Reverberation and multipath occur in active systems that transmit sound energy such as sonars, positioning systems and is due to the interaction of the ocean environment with the transmitted acoustic signal. Reverberation is the reradiation of incident sound energy by material suspended in the water or due to physical boundaries. It manifests itself as a realtively slowly decaying ragged tonal envelope following the ping or a strong reflective return of an active system. Reverberation is divided into two categories which are modelled somewhat different mathematically - surface reverberation and volume reverberation. Reverberation levels may be estimated from:

$$RLv = Sv + SL - TL + 10\log(ct_p\Omega_B/2)$$

where RLv is the received volume reverberation level (dB)
Sv is the volume scattering coefficient (a large variable ranging typically from -60 to -90 dB)
SL is the transmission level
TL is the transmission loss
c is the velocity of sound
t_p is the pulse with
Ω_B is the transducer solid angle beam-width.

A similar equation exists for surface reverberation. Multipath is similar in nature to reverberation and is a strong single or multiple distinguishable echo that can cause interference with the primary signal in acoustical communications systems such as transponders or telemetry/ telephony equipment. Problems from this source arise with systems with long pulse durations and/or proximity to strong reflectors such as the bottom and surface.

Transducer and Electronic Self Noise

The final noise source that will be discussed are the self generated noises of the hydrophone and its associated amplifier.

Transducer Self Noise

The noise source generator associated with the transducer alone is due to internal mechanical and electrical losses which at the electrical terminals appears as a resistive component in the impedance of the device. This resistance is a generator of electrical noise according to the formula:

$e_n = \sqrt{4kTr\,\delta f}$ where k is Boltzmans constant 1.38×10^{-23}
T is temperature (deg K)
R is the resistive part (ohms)
δf is the bandwidth of the system (Hz)

The resistive component of the impedance of a hydrophone is a complex function of environment (i.e. whether the hydrophone is in air or water) and of frequency. In water the resistive component should theoretically increase due to the radiation resistance of the water with which the transducer is coupled. According to Urick the noise voltage generated by this resistance should agree with the thermal noise level of the ocean when the transducer efficiency is accounted for. A measurement of the resistive component alone however does not give a complete representation of the noise performance since the hydrophone sensitivity must also be taken into account. A more useful measure of performance of the hydrophone (or hydrophone - preamp combination) is given by what is termed the Equivalent Noise Pressure Level which is the acoustical pressure level that would generate a voltage level equal to that generated by the systems self noise, per unit bandwidth. It may be calculated from:

$$NL_\epsilon = 20\log(e_n) - HS$$

where e_n is the voltage noise level of the transducer and HS is the hydrophone sensitivity in dB. Generally, however, one can usually assume that self generated transducer noise is very low and well below the ambient noise levels due to other sources.

Amplifier Noise

In most systems the component that determines the electronic noise contribution is the first stage of amplification following the transducer, known as the preamp. Fortunately for the acoustics systems designer, recent developments in low noise solid state devices, particularly in the field of operational amplifiers, have made good noise performance in many instances readily obtainable. This is particularly true for the acoustic spectrum below 20 KHz where the ambient ocean noise will tend to mask the preamp's electronic noise. Above this frequency hydrophone/preamp noise could well be above minimum ocean ambient levels, especially for low sensitivity calibration hydrophones such as B & K 8103/8104 which tend to sacrifice sensitivity for a smooth frequency response. Transducers (hydrophones) however which are operated at or near their resonant frequency will usually exhibit much higher sensitivies. In all cases however the effects of the transducer and any other input electrical components on preamplifier noise performance should be examined before the input device is chosen, which will be a choice between bipolar or junction field effect transistors. The guideline here is the impedance of the transducer and any other associated input circuitry - above 10KΩ the FET is generally favoured and below the bipolar.

Cable too can have a degrading effect on noise performance by loading the transducer so that the preamp should be located as close as possible to the transducer.

Finally the components of the acoustical system should be what I will call "noise matched". There is little point in striving to provide components (e.g. preamps) that are much below the noisiest part of the overall system. For example providing a noiseless preamp to replace one that contributed a noise level equal to that of the ocean environment would only result in a 3 dB improvement in the total noise level which would result in no significant improvement in most systems. Similarly any digitizers should have a resolution limit comparable to the noise level of the system.

Some Methods of Minimizing Noise

The three methods of minimizing noise I will mention all fall under the broad category of filtering. In the frequency domain one should limit the system frequency response to that necessary for the task at hand. Excessive frequency responses not only allow in more noise but also can lead to subtler problems involving overloading or other spurious signals due to inherent system nonlinearities. Spatially one can also provide filtering by using directional transducers. The degree of effectiveness of the directionality of a transudcer is given by a parameter called the directivity index (DI) and is the amount in dB by which isotropic noise is reduced. The directivity index is usually a function of frequency so that the technique is limited to narrow band systems, and many systems are required to be virtually omnidirectional so its usage is not universal. Finally, digital techniques such as averaging and correlation may be used in more sophisticated systems that will allow a signal to be received with a negative signal to noise ratio.

Doppler Current Profilers

N.A. Cochrane, John W.E. Whitman and Donald Belliveau
Bedford Institute of Oceanography
Dartmouth, Nova Scotia

Introduction

The Bedford Institute of Oceanography presently employs three Doppler Current Profilers (DCPs):

1) An AMETEK STRAZA DCP4400/300 300 kHz "portable" system purchased in 1982. This system has been hull or boom mounted on eight different vessels.

2) An AMETEK STRAZA DCP4400/300A (high power output system) purchased in 1984 and permanently mounted on C.S.S. DAWSON. The bulk of our developmental work has taken place on this instrument.

3) An RD INSTRUMENTS RD-SC150 bottom mounted profiler purchased in 1986. This unit is currently (winter 1987-88) deployed in the Gulf of St. Lawrence to measure ice movement in an upward looking mode. A second RD-SC150 will be delivered in 1988.

Areas Requiring System Development

AMETEK Profilers

The AMETEK STRAZA profiler consists of two distinct entities: a) a proprietary electronics package which performs the initial extraction of beam Doppler counts; b) a system controller computer (manufacturer supplied HP-85) which performs the subsequent data reduction and display. System development efforts have involved a) upgrading electronics package functions by ongoing or commissioned manufacturer upgrades and b) improving the quality and efficiency of ocean current data extraction by in-house upgrades and extensions to the system controller.

Shortcomings of both the DCP4400 and DCP4400A systems center about four areas: 1) inadequate ability to efficiently log and process data (up to 45% of data lost); 2) simplistic processing algorithms demanding that vessels steam a straight line path; 3) lack of ship motion compensation and 4) intractability - limited self test and no real time fault monitoring.

RDI Profiler

The RDI profiler requires a safe trawling-proof bottom mount which is easily deployed and recovered.

Resolution of Problem Areas

AMETEK Profilers

In 1982 HP-85 software was modified to log AMETEK raw data including navigation feeds to the ship's minicomputers. This enabled post processing but did not eliminate significant data-loss unless all real-time processing was curtailed. Concurrently off-line analysis software was written to post process logged raw data with full "geodetic averaging" allowing the ship to manoeuvre at will. Updated versions of this system now reside on our μVAX II shipboard minicomputers for demanding applications.

Although off-line processing provided geodetic averaging, the inconvenience of post processing large volumes of data and the remaining shortcomings noted above dictated upgrading the system controller (Whitman et al., 1987). Resultant design objectives are shown in Table I. An enhanced speed IBM-PC/XT was chosen as system controller. Selected hardware components are listed in Table II. A 50 s period counter-balanced pendulum motion sensing package originally developed for moored yacht hull measurements was adapted as an inertial reference to enable ship motion compensation. The pendulum supplies pitch and roll data from resistive potentiometers together with three components of linear acceleration furnished by accelerometers stabilized within the pitch and roll axes. Inertial components are digitally sampled at 10 Hz following notch filtering at the pendulum resonant frequency. These components include the analogue intergrals of the horizontal accelerations which yield translational velocities and the double integral of vertical acceleration giving vessel heave. Generally ship accelerations can be accurately recovered to periods as long as 15 s which appears sufficient for most operational conditions.

The theory of both static and dynamic motion compensation is outlined by Cochrane and Whitman (1987). At present we have implemented static motion compensation, including vessel heave vertical datum corrections, in the post processing mode. In the real-time mode, full data recovery and logging is achieved simultaneous with geodetic average processing, and data consistency/screening checks (Table I). Computer simulation indicates static motion compensation should significantly reduce vertical smearing of velocity profiles arising from vessel pitch and roll induced deviations in Doppler transducer orientation. Dynamic correction is useful only for specialized high time resolution measurements and is considered of lower priority for field applications.

Apart from enhanced performance, an important system consideration is user friendliness and ease of data extraction. It is planned to incorporate a Human Interface Module which will interact with the user allowing configuration of the AMETEK electronics package and the selection of data processing parameters from disk-resident tables. This will allow essentially "turn-key" operation when desired. Either raw or processed data can be stored to tape or logged to the shipboard μVAX in a standard archival format. We have chosen to log processed data (PRO-DCP) in a traditional mechanical current meter database format allowing easy use or adaptation of pre existing software. Velocity section contouring now operational on the μVAX may be implemented in real-time as processed data is logged. In any case traditional graphic plots of velocity vs depth will be produced. Provision exists for post processing logged raw data with the same software as in real-time usage. This enables the system to be utilized as a flexible research tool to assist incorporation of more advanced motion compensation algorithms, data quality screening, and display techniques.

#	OBJECTIVE	STATUS
i	Collect all of the DCP data without any loss of pings.	FF
ii	Save all pings to 9-track tape with LORAN-C information.	FF
iii	Measure the ship's motion and log this information to 9-track tape accurately time stamped to correspond with DCP data.	FF
iv	Process each ping and display immediate values such as ping status, heading, temperature, pitch, roll and heave etc.	FF
v	Compute, store to disk, plot, and tabulate geodetic current profiles for an ensemble of pings.	FF
vi	Monitor the DCP for consistency - basic tractability test.	FF
vii	Perform static ship's motion compensation on a ping-by-ping basis. Screen pings to eliminate outliers.	PP
viii	Perform dynamic ship's motion compensation.	NO
ix	Ensure DCP tractability by performing advanced DCP monitoring with the assistance of a second microcomputer equipped with digital multi channel oscilloscope capabilities.	NO
x	Provide versatile graphical data presentation including time series and contouring.	NO

Table I: Design objectives for the SMC-DCP system. STATUS indicates the current achievement status for each objective as Fully Functional (FF), functional in the Post-Processing mode only (PP), or as Not Operational (NO).

MICROCOMPUTER	PERIPHERALS
IBM-PC/XT MICROCOMPUTER : - 10 MHz 8086 CPU and 8087 math co-processor. ("Number Smasher" board by Microway) - Hercules monochrome graphics adapter card. - IEEE-488 card("PC-488" by Capital Eqpt.Corp. one card to interface to the DCP and a second for the 9-track tape) - "Lab-Master" analog to digital converter by Tecmar, with digital inputs, timer, and 16 channel 12 bit resolution. All channels sampled ten times per second. **SOFTWARE:** - Microsoft Pascal version V 3.32. - No-Limit Pascal support library by MEF Environmental Inc. - Graph-X support library for the Hercules graphics card by Hercules Computer Technology. - Firmware resident support procedures for the CEC PC-488 interface card. - Microsoft Macro Assembler. **SECOND COMPUTER SYSTEM:** - IBM-PC/XT compatible microcomputer with a 10 Mbyte hard disk and 8 MHz. CPU. - IBM CGA graphics card and monitor.	**PRINTER :** - Panasonic model KX-P1595. (high speed Epson FX-80 compatible) **9-TRACK TAPE DRIVE:** - IDT model GPIB 1050. (1/2 inch NRZI/PE at 800 / 1600 bpi. IEEE-488 interface) **MOTION SENSING PACKAGE:** - High inertia, long period (50 s) counter-balanced pendulum supporting a reference platform [4] (in-house). - Setra model 141A accelerometers mounted on the stabilized platform sensing fore, starboard, and down components of ship's acceleration. - Analog signal conditioning unit including differential instrumentation grade line amplifiers, notch filters, low-pass filters, and analog lossy integrators. (in-house) **SECOND COMPUTER SYSTEM:** - RC Electronics Inc. model ISC-16 Computer-scope. 16 channel digital oscilloscope card monitoring the DCP XMIT, CYCLE, BIN STROBE and AGC signals programmable in IBM BASIC. - CEC model PC-488 IEEE-488 card communicating tractability indicators to the first computer system.

Table II: Detailed SMC-DCP components list.

Future objectives include the incorporation of a separate PC as a real-time system health/fault monitor which will report to the primary system controller. The monitor PC will incorporate a 16 channel digital oscilloscope card to monitor electronics package voltages and functions.

RDI Profiler

The requirement exists to protect bottom moored instruments from trawling operations. To this end a special bottom housing has been developed and initially tested (Dessureault and Belliveau, 1987). This consists of a 4.05 x 3.35 m semi rectangular 700 Kg aluminum box with inward sloping sides. An inner buoyant package containing the RDI is realeased on acoustic command carrying a line to the surface. The top of the package is covered by 1/2 inch polyethylene. On deployment the sides dig into sediment allowing trawls to slip over the package. The embedding in bottom is monitored with a TV camera mounted on the main deployment cable.

Acknowledgement

This work is supported by the Office of Energy Research and Development (OERD) of the Department of Energy, Mines, and Resources, Project No. 67128.

References

Cochrane, N.A. and J.W.E. Whitman. 1987. Motion Compensation for a Shipboard Doppler Current Profiler, Considerations and Implementation. In: Proceedings IEEE OCEANS' 87, pp. 117-122.

Dessureault, J.-G. and D. Belliveau. 1987. A Trawl-Proof Housing for Bottom Mounted Instruments. In: Proceedings IEEE OCEANS' 87, pp. 658-660.

Whitman, J.W.E., N.A. Cochrane and D. Belliveau. 1987. A Microcomputer System for a Shipboard Doppler Current Profiler. In: Proceedings IEEE OCEANS' 87, pp. 104-109.

Discussion on "Aspects of Systems Engineering" Session

James L. Galloway, P. Eng.
Institute of Ocean Sciences
Sidney, B.C.

Development of effective acoustic systems has often been regarded as a "black art". Successful acoustical engineers were viewed as those individuals hidden away in the back room who magically made the sonar system actually work. Much of this image came from the lack of formal training available to engineers working with acoustics and a subsequent need for extensive self-education of these individuals. Until recently, there was a limited selection of good textbooks in the field with Principles of Underwater Sound by R.J. Urick regarded as the "bible", but in recent years a number of texts have appeared which cover the subject fairly thoroughly so that the required knowledge is readily available. Suitable textbooks, coupled with graduate level courses in acoustics at Universities such as UVIC and Memorial, have alleviated some of these difficulties so that, today, more systematic engineering approaches are taken to the systems engineering of acoustic based projects.

Three papers were presented in this session:

1) Swath Survey Systems by Bob Burke:

Bob received the M.E. in Elec. Eng. from TUNS and is currently Head, Hydrographic Development, BIO.

Bob described the difference between sweep and swath systems noting that sweep systems have numerous individual transceivers and are optimized for shallow (<100 metres) waters. He then provided an excellent review of the history of sweep systems development, from Europe to the U.S. and in Canada. From his review, it is apparent that Canada is a world leader in sweep system development. The F.C.G. SMITH design criteria were outlined, then translated to a workable ship. Bob's paper concentrates on the F.C.G. SMITH and the sounding equipment installed.

Question highlight: Could sweep systems be used as systems of opportunity for fisheries acoustics, especially since systematic hydrographic surveys are conducted in areas of interest to biologists?

Answer: Not as currently configured since the raw acoustic signal is not available for all channels but, since the signals are present within the sounders, they could be brought out.

2) Noise in Acoustic Systems by Jim Parks:

Jim received the B.A.Sc. in Elec. Eng. from UBC and is currently a Project Engineer with Engineering Development, IOS.

Jim defined what is meant by noise when applied to acoustic systems and characterized the numerous and varied noise sources of the world's oceans including wind, waves, rain, biology, cracking ice, thermal, and shipping. Groundwork was laid with the definition of the decibel which is universally used in acoustic systems design. Finally, Jim gave examples of how to properly handle, in a mathematical sense, electronic and acoustic noise sources together in a system.

Question highlight: Is the intensity reference provided in the overhead correct since it appears different than other sources?

Answer: The primary reference in underwater acoustics is $P_0 = 1$ uPa which is a pressure unit whereas intensity I_0, which is a power density, is a derived reference calculated from P_0, density, and sound speed where density and speed vary slightly with location, thereby resulting in small differences in I_0.

3) Doppler Current Profilers by Norman Cochrane

Norman received the Ph.D. in Geophysics from Dalhousie and is currently a Research Scientist with Metrology, BIO.

Norman described the principle of operation of doppler systems using the Janus configuration as an example. Two Ametek Straza and one RD Instruments doppler profilers were described along with some applications of the systems. Impact of ship motion on doppler data was modelled in some detail to characterize resulting errors in measurements and the custom pitch/roll/heave sensor was described. The current HP-85 computer will soon be replaced with an IBM-PC to greatly enhance performance of the Ametek Straza units. A unique trawl-proof bottom mooring assembly developed for the RDI doppler profiler was shown.

Question highlight: Why was a pitch/roll/heave sensor system built when they are available off the shelf?

Answer: This package existed prior to the doppler work and our modelling efforts showed it to be adequate for our purposes, keeping errors to within one metre/second at 200 metres depth for pitch and roll of 4 and 7 degrees respectively. Also, the cost of commercial sensors is very high.

Wrapup

Although the acoustical engineer has lost his mystique and has come out of the "back room", the successful operation of acoustic systems is still very dependent upon this individual. Many successful projects can be tied to the dedication of a single "champion", an individual who applies himself totally to the solution of all the project problems, technical and otherwise. The authors in this session qualify as members in the champion club!

Fisheries Acoustics in the High Arctic: Under-Ice Applications

R.E. Crawford

Abstract

Arctic cod occupy a pivotal role in the High Arctic food web. It is the main pathway in the transfer of energy between zooplankters and marine mammals, birds, and larger fish. An understanding of the Arctic ecosystem requires an understanding of the biology and population dynamics of this fish.

In 1984, Central and Arctic Region initiated a study of Arctic cod with the objective of examining its biology, seasonal distribution and abundance. To accomplish the initial phases of this work, hydroacoustics was selected as the method of choice because much of the Arctic cod habitat in the study area is beneath landfast sea ice for much of the year. The study was begun in the eastern Northwest Passage near Resolute Bay and now includes the nearshore Beaufort Sea.

A dual-beam hydroacoustic system has been assembled for deployment on sea ice from a komatik, helicopter or small boat, depending on the season and area of operation. The transducer is suspended beneath the ice on a pivoting rotator which allows searching the water column at angles between and including horizontal and vertical. After ice break-up, the system is operated conventionally from a small boat, with the transducer mounted in a towed body.

Testing has shown that a circular beam transducer is capable of detecting a fish swimming within 0.5 m of the sub-ice surface. Melt stellactites increase this distance of detection. Horizontal search range is limited to a distance slightly greater than the water depth. The most effective horizontal search pattern is a stationary search which waits for moving targets to enter the acoustic beam.

Results in 1985 indicated that most Arctic cod-size targets (-59dB to -41dB) were distributed near the bottom. The total number of targets observed that year was low.

In 1986, targets were much more abundant and were distributed throughout the water column. At many sites, there was often a significant trend in increasing target size with depth. But there was also evidence that this behaviour was influenced by tidal currents. When the tide was slack, smaller targets were distributed further into the water column.

Ice conditions and the location of the land fast ice-edge were quite different in the study area for the two years.

The development of a groundtruthing program for sampling under ice has awaited the collection of data on fish distribution and behaviour. Gill netting has proven to be effective and a hydroacoustically triggered underwater camera is presently under development.

Introduction

Application by Central and Arctic Region of hydroacoustic technology under the ice in the High Arctic, specifically in the eastern Northwest Passage area, has been in response to burgeoning offshore hydrocarbon development. The eastern Arctic is a potential route for hydrocarbon transport to southern markets, particularly by icebreaking tankers. There is concern for the food chain in the event of a marine disaster in this area. Contingency plans to minimize the potential impact of any such disaster require information which is presently lacking.

In an effort to increase knowledge of the Arctic marine food chain, a study of marine fish and squid in the eastern High Arctic was begun in 1984. As a matter of focus, most effort has been directed toward studying the biology, abundance, distribution, and productivity of Arctic cod, Boreogadus saida. This species is thought to occupy a pivotal position in the Arctic marine food chain, both nearshore and offshore. It is believed to play an extremely important role in the transfer of energy from the abundant small zooplankters to marine mammals, larger fish, and birds.

Because of the obvious logistic problems of studying fish distribution beneath sea ice, hydroacoustics was selected as the primary method by which to begin our examination of Arctic cod. Our plan called for preliminary surveys to gather information on the habits and distribution of these fish. As our knowledge increased, we would focus on more specific studies to derive estimates of Arctic cod production and descriptors of population dynamics.

Description of Hydroacoustic System and Its Application

A portable dual-beam hydroacoustic system was adapted for field use in the Arctic. The field unit consists of a transceiver, a graphic recorder, a digitizer and magnetic recorder, and various interfaces and test equipment. It was configured for deployment from a komatik (a sled pulled by a snow machine), a helicopter, a Twin Otter aircraft, or a boat.

Our deployment of this system is a departure from normal fisheries acoustics application in that the transducer is stationary beneath the stable sea ice platform. It is suspended in a rotatable pivoting mount which allows horizontal through vertical searches under the ice. We leave the beam fixed in one direction and record data as targets pass through the beam.

The dual-beam system allows determination of several parameters including: target strength, target depth, distribution of target size in the water column, rate of target passage through the beam, and the angle of target passage through the beam.

Another advantage of stationary deployment is the ability to track individual targets as they pass through the acoustic beam. Tracking allows averaging measurements from individual targets, a method of reducing ping-to-ping variation in target strength to enhance the accuracy of estimation. We are sometimes able to get as many as several hundred measurements from individual distant targets (e.g. ranges 100 m).

We also use echo counting and echo integration to derive estimates of target density.

Survey Techniques and Results

To establish our capability to detect fish targets near the sub-ice surface, we tested our system's performance in detecting ping pong balls under ice. These tests revealed that:

1. horizontal search radius was limited to slightly more than the water depth, probably due to transmitted side lobe energy being reflected to the bottom;
2. ping pong balls suspended from holes in the ice were not easily detected due to the echo received from the hole itself;
3. fish-sized targets were detectable within 0.5 m of a smooth sub-ice surface.

In 1985, fish-sized targets in the water column were rare. In 1986, targets were scattered throughout the water column.

During both surveys, targets near ice were rare. Targets were much more frequently detected near the bottom. Because species diversity is so low and Arctic cod are by far the most predominant fish in these waters, we assume that most fish-sized targets are Arctic cod.

Single fish-sized targets are common. We use 200 kHz which allows improved resolution of these single targets, although we sacrifice maximum range capability. Because we use 200 kHz, higher gain settings allow detection of zooplankters, particularly the large copepods and amphipods abundant in the Arctic fauna. We often detect layers of ctenophores, amphipods and copepods responding to internal waves passing beneath the ice. These components can be identified with a drogue plankton net suspended in the currents at various depths.

From each station we obtain a distribution of target strengths detected. By comparing the target strength distributions among stations, we are able to look for differences in the utilization of different areas by different age classes. For example, we observe a significantly higher proportion of smaller fish (i.e. younger fish) in certain bays. We interpret this to suggest that these areas may be nursery habitat for Arctic cod.

We also examine the distribution of targets by depth. At many stations, the distribution of target strength, where each data point is the average target strength of at least five measurements per target, reveals a significant shift toward larger targets as depth increases. With rare exceptions, largest targets are within several metres of the bottom.

There is an apparent tidal component in the distribution of target size by depth. When each of a series of observations, made at the same site during a tidal cycle, is examined separately, there is a periodicity in target distribution. This suggests that during high tidal flows, smaller targets are more abundant near the bottom and at the sub-ice surface.

Discussion and Future Prospects

Groundtruthing of the echoes we detect beneath ice is a difficult problem. We have tried baited fish hooks, but unsuccessfully. We have had limited success with a video camera. We have also had some success with gill nets, but high currents in the Arctic Archipelago makes use of gillnets a challenge. Our present efforts toward identifying high-density targets beneath ice are focused toward development of a hydroacoustically triggered camera. A target passing through only the camera's area of focus is detected acoustically and can trigger the camera and light source if proper signal threshold criteria are met. The camera is oriented orthogonally to current flow because video observations suggest Arctic cod display rheotactic behaviour and such orientation will provide the best photographs.

Tests with an early prototype indicate that we will have some success with this device, particularly in identifying targets near the bottom. A major advantage in using this camera through ice is the stability of the ice surface. The camera can be suspended practically motionless anywhere in the water column.

The waters in the eastern Arctic study area have never been systematically surveyed for fish and we have only limited knowledge of the fauna in this area. Our camera will help but we expect our knowledge of this fauna will expand quickly when a proper open-water groundtruthing platform in the form of the MV OGAC becomes operational, perhaps in 1989. The OGAC was designed as a fisheries acoustic research platform for use in the Eastern Northwest Passage. Its delivery to that area and the completion of the development of our groundtruthing camera will go a long way toward providing us with means to relate target strength, location and behaviour to target identification.

Until these tools become operational, we will continue using hydroacoustics in studies such as the synoptic distribution of targets in the study area and their behaviour in various tidal regimes to further our understanding of marine fish in the eastern High Arctic.

Two Acoustic Measurement Techniques for Recording Fish Movements During Migration

K.D. Cooke
Pacific Biological Station
Nanaimo, B.C.

Abstract

The use of time-lapse video recording in combination with side-scan sonar and ultrasonic transmitters are discussed as two means of observing juvenile and adult sockeye salmon (Oncorhynchus nerka) migration. Information on direction, speed, depth and time of movement are obtained in this manner.

The time-lapse recording of the scanning sonar signal allows for compression of time and thus, during playback, facilitates separation of moving targets from stationary ones. Two systems are examined; one in a freshwater environment and the other in a marine location. Information on target identification is provided through capture of ensonified fish and through differences in behavioural characteristics of the targets.

Migration of adult sockeye salmon are reported in coastal and estuarine waters using depth sensing ultrasonic transmitters and position locator transmitters. We used transmitters with frequency ranges of 50-76.8 kHz inserted internally into the fish's stomach. Salmon equipped with a sonic tag were followed from a boat with a directional hydrophone at about 100-500m distance. Tracks of sonic tagged adult fish in relation to "in situ" environmental parameters are examined. Variation in migration behaviour in relation to oceanographic regimes is discussed.

The use of scanning sonar in combination with time-lapse video recording and ultrasonic tracking are two means of monitoring fish movement. Both of these techniques have been used to study the migratory behaviour of juvenile and adult sockeye salmon (Oncorhynchus nerka) in the freshwater and marine environments (Groot 1972, Groot et al 1975, Groot and Wiley 1965, Luke et al 1973, Madison et al 1972, Quinn and terHart 1987, Quinn et al 1988, Stasko et al 1976). Information on direction, speed, depth and daily timing of movement are obtained in this manner.

1. Time-Lapse Recording of Sonar Observations

Juvenile sockeye salmon migrate to sea generally after spending one year in a freshwater nursery lake. In the Babine Lake system in north-central British Columbia, juveniles from three separate spawning populations move downstream to the lake outlet from about mid-April through June. In 1963, sonar observations were made at various locations on the lake to study the migratory behaviour of these smolts (Fig. 1a, Groot 1972, Groot and Wiley 1965). A Honeywell sea scanner Model 1B was used with an operating frequency of 132kHz. The radiated beam was an 8° cone which translates to a diameter of about 18m at 125m distance (Fig. 1b). The echo signals displayed on the PPI scope were recorded with time lapse photography such that each 180° scan of the sonar was preserved on a single frame of 16mm film. At a range of 125m, one complete scan lasted 11.3 sec. When this film record is displayed at a speed of 24 frames/sec, a 24 hr. period can be viewed in 2 1/2 min. Echo signals of moving targets recorded during subsequent scans appear slightly displaced on following frames in a pattern related to the actual movement of the target. The individual target positions are manually plotted from the screen to determine target movement, direction and speed. Figure 2 depicts plots which represent the tracks of individual targets at different times of the day obtained from frame-by-frame analysis of the sonar film (Groot 1972). The accompanying scatter diagrams illustrate the directions of movement and mean directional tendency. Two periods of intensified migration were evident: 1) after sunset between 2130 and 2330 hr. and 2) immediately before and for a short time after sunrise, between 0300 and 0500 hr. (Groot 1972). Catch records at the fence located downstream of this sonar site also reflect this pattern of activity.

Information on timing, intensity, speed and direction of migration over 24 hr. periods can be extracted from hourly series (Groot 1972). The speed of migration of 18 schools migrating between 2200 and 2215 hr. was from 16cm/sec to 75cm/sec with an average of 32cm/sec. Direct measurements of speed of near surface migrating schools revealed velocities between 20cm/sec and 30cm/sec with a mean of 25cm/sec. When operations are extended through the entire migration period, seasonal variations of these parameters can be obtained.

In 1987 we used a Wesmar 265 color sonar, operating at a frequency of 160kHz, to observe the seaward migration of sockeye smolts through Alberni Inlet on the west coast of Vancouver Island. Scanning ranges varied from 30m to 100m. The radiated beam pattern approximates a 6.5° cone and was projected from about 2m depth at an angle of 4° below the surface. Echo signals were recorded on a JVC BR9000U time-lapse VCR at time compression of 60X, which allows for viewing of a 24 hr. period in 24 min. when replayed at normal speed.

2. Sonic Tagging

In 1985 and 1986, we undertook a study to determine how the migration routes of adult sockeye salmon returning to the Fraser River are affected by changes in oceanographic conditions such as temperature, salinity, and current patterns (Groot and Quinn 1987). To monitor the behaviour and movement of the fish, we used depth-sensing ultrasonic transmitters as position locators of individually telemetered fish. By tracking sockeye salmon equipped with depth-sensing transmitters and concurrently recording vertical profiles of temperature, salinity, and current speed and direction (Quinn and terHart 1987, Quinn et al 1988), we were able to describe the movements of fish in relation to their immediate environment.

The pressure-sensitive transmitters (Vemco Ltd., Nova Scotia) used ranged in frequency from 50 to 76.8 kHz with the interval between pulses directly proportional to water depth (Vemco, Ltd., Nova Scotia). We calibrated the transmitters to a depth of 50m at an accuracy of 1m. Transmitters were implanted in the stomach of sockeye salmon captured by purse seine. The fish were tracked with a directional hydrophone and Model VR-60 receiver/decoder (Vemco, Ltd., Nova Scotia). Transmitter range varied between 100 and 500 m depending on local conditions and individual transmitter output. Horizontal position was recorded as the ship's location determined by Loran C (RayNav 550, Raytheon Inc.), radar and local landmarks.

The study area progressed southward through three regions with distinct oceanographic properties. The Queen Charlotte Strait-Johnstone Strait region has cold, saline water with weak stratification. The waters in the second region, Discovery Passage, are almost homogeneous as a result of thorough mixing by strong tidal streams flowing through narrow channels and over shallow sills. The third region, the Strait of Georgia, is strongly stratified, warmer and much less saline than the waters to the north (Fig. 3, Thomson 1981, Thomson et al 1985). The complexity of each of the regimes are compounded by the variable tidal flow. Flooding tides progress southward in the northern and central portions of the study area and northward in the southern portion. The opposing floods meet in the northern Strait of Georgia.

Figures 4 and 5 (adapted from Quinn et al 1988) illustrate two salmon tracks representative of fish movement in two of the oceanographic regions of the study area. Sockeye salmon had a general preference for near-surface water, as was evident from their shallow distribution in the mixed regions; in waters with more distinct vertical structure, they were located at or near the depth where temperature and salinity gradients were largest (Fig. 6, adapted from Quinn et al 1987). However, we observed considerable variation in this pattern, both within and between oceanographic regimes. The estimated average swimming speed was 66.6 cm/sec (2.40 km/h) with an average displacement of 24 km/d (Quinn et al 1987). Tag returns of telemetered and non-telemetered fish lead us to believe that our handling of the fish and insertion of the transmitters did not unduly affect their behaviour.

Acoustic measurements provide an effective means of obtaining information on movement of groups of fish, while sonic tracking provides detailed information on individual animals. Each of these methods has its shortfalls. We are still groping with interpretation of echosignals and their relation to fish size and species. Further research into target identification and continued development in signal processing techniques may provide us with species specific echo signatures and lead to greater accuracy of biomass estimation. Advancements in transmitter design, life expectancy and signal range will improve the application of this technique to other ethology studies.

References

Groot, C. 1972. Migration of Yearling Sockeye Salmon (Oncorhynchus nerka) as Determined by Time-Lapse Photography of Sonar Observations. J. Fish. Res. Bd Can. 29: 1431-1444.

Groot, C. and T.P. Quinn. 1987. The Homing Migration of Sockeye Salmon to the Fraser River. Fish. Bull. 85: 455-469.

Groot, C., K. Simpson, I. Todd, P.D. Murray and G.A. Buxton. 1975. Movements of Sockeye Salmon (*Oncorhynchus nerka*) in the Skeena River Estuary as Revealed by Ultrasonic Tracking. J. Fish. Res. Bd. Can. 32: 233-242.

Groot, C. and W.L. Wiley. 1965. Time-Lapse Photography of an ASDIC Echo-Sounder PPI-scope as a Technique for Recording Fish Movements During Migration. J. Fish. Res. Bd. Can. 22: 1025-1034.

Luke, D. McG., D.G. Pincock and A.B. Stasko. 1973. Pressure-Sensing Ultrasonic Transmitter for Tracking Aquatic Animals. J. Fish. Res. Board Can. 30: 1402-1404.

Madison, D.M., R.M. Horall, A.B. Stasko and A.D. Hasler. 1973. Migratory Movements of Adult Sockeye Salmon (*Oncorhynchus nerka*) in Coastal British Columbia as Revealed by Ultrasonic Tracking. J. Fish. Res. Bd. Can. 29: 1025-1033.

Quinn, T.P. and B.A. terHart. 1987. Movements of Adult Sockeye Salmon in British Columbia Coastal Waters in Relation to Temperature and Salinity Stratification: Ultrasonic Telemetry Results. Can. Sp. Publ. Fish. Aquat. Sci. 96: 61-77.

Quinn, T.P., B.A. terHart and C. Groot. 1988. Migratory Orientation and Vertical Movements of Homing Adult Sockeye Salmon (*Oncorhynchus nerka*) in Coastal Waters. Anim. Beh. (in press).

Stasko, A.B., R.M. Horrall and A.D. Hasler. 1976. Coastal Movements of Adult Fraser River Sockeye Salmon (*Oncorhynchus nerka*) Observed by Ultrasonic Tracking. Trans. Amer. Fish. Soc. 105: 64-71.

Thomson, K.A., B.A. terHart and P. Welch. 1985. CTD Survey of the Inside Passage of British Columbia, June 1985. Dept. Ocean., Univ. of British Columbia MS Rep.

Thomson, R.E. 1981. Oceanography of the British Columbia Coast. Can. Sp. Publ. Fish. Aquat. Sci. 56: 1-291.

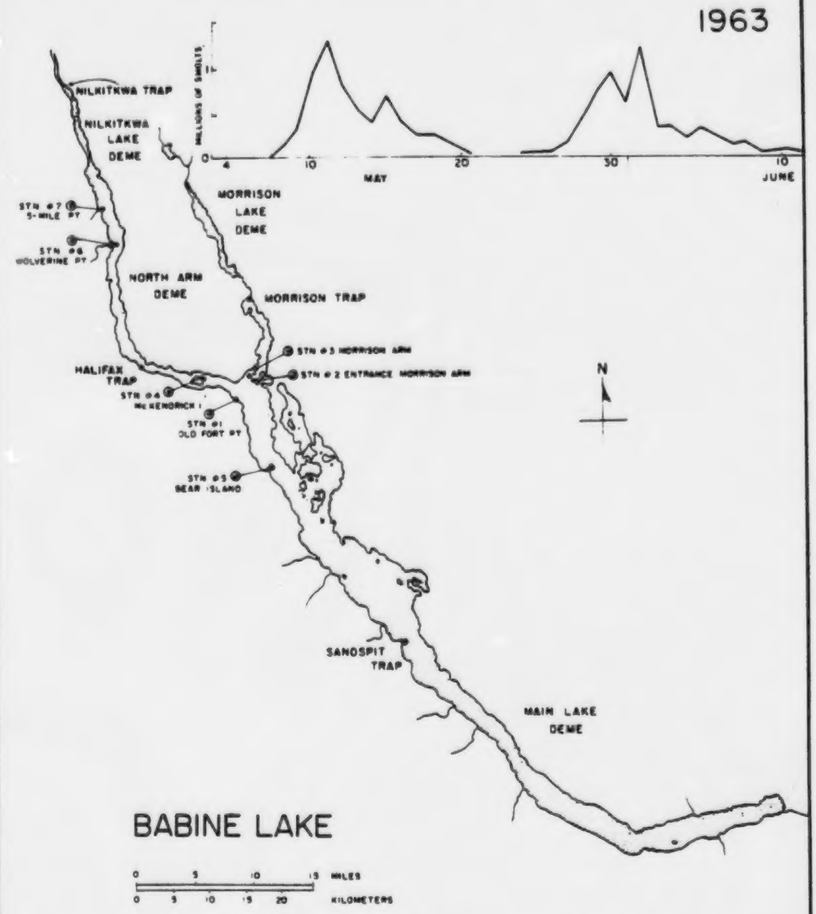

1963
MILLIONS OF SMOLTS
0
1
4
10
20
MAY
30
10
JUNE
NILKITKWA TRAP
NILKITKWA
LAKE
DEME
MORRISON
LAKE
DEME
STN #7
5-MILE PT
STN #6
WOLVERINE PT
NORTH ARM
DEME
MORRISON TRAP
STN #3 MORRISON ARM
STN #2 ENTRANCE MORRISON ARM
HALIFAX
TRAP
STN #4
McKENDRICK I
STN #1
OLD FORT PT
STN #5
BEAR ISLAND
N
SANDSPIT
TRAP
MAIN LAKE
DEME
BABINE LAKE
0 5 10 15 MILES
0 5 10 15 20 KILOMETERS

Fig. 1a: Babine Lake study area showing distribution of the three demes of sockeye smolts and the sonar stations.

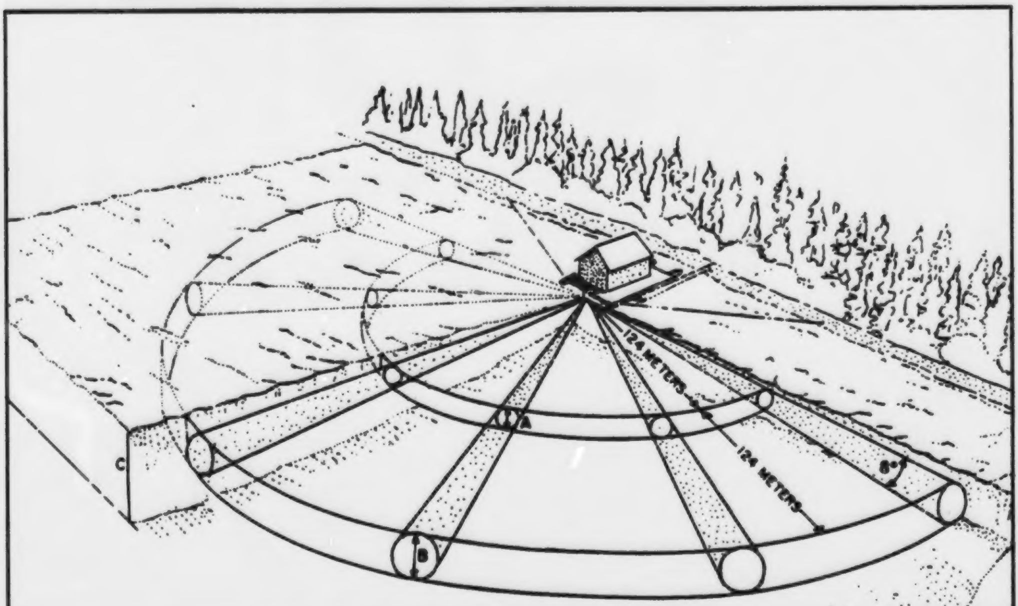

C
A
124 METERS
124 METERS
8°
B

Fig. 1b: Diagram of scanning arrangement with the sonar barge anchored to shore.

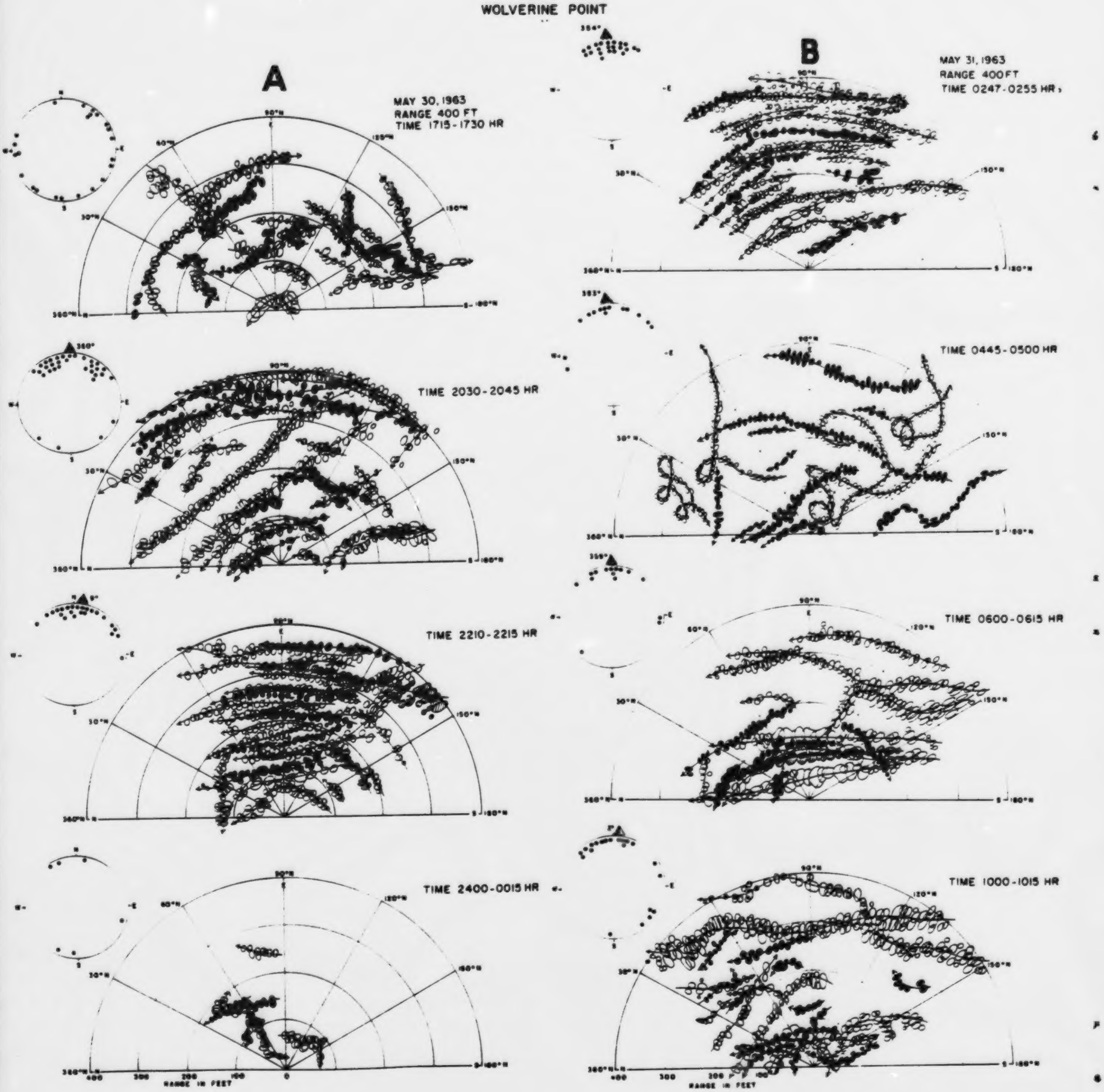


Fig. 2: Movements of targets at different times of the day obtained from a frame-by-frame analysis of a sonar film taken at Wolverine Point, May 30-31, 1963. Scatter diagrams illustrate directions of movement (one dot for direction of first part of each track) and mean directional tendency (▲) in degrees north.

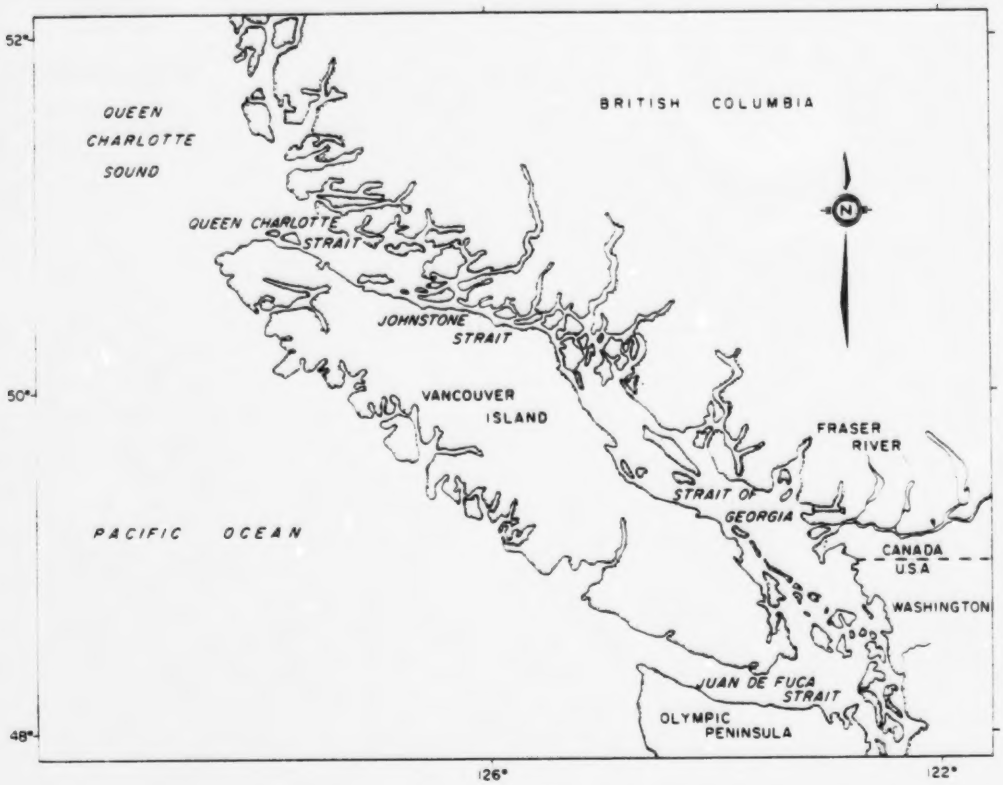

52°
50°
48°
126°
122°
QUEEN CHARLOTTE SOUND
BRITISH COLUMBIA
QUEEN CHARLOTTE STRAIT
N
JOHNSTONE STRAIT
VANCOUVER ISLAND
FRASER RIVER
STRAIT OF GEORGIA
PACIFIC OCEAN
CANADA
USA
WASHINGTON
JUAN DE FUCA STRAIT
OLYMPIC PENINSULA

Fig. 3: Map of Vancouver Island, British Columbia showing area of tracking and three distinct oceanographic regions: 1) Queen Charlotte Strait-upper Johnstone Strait, 2) lower Johnstone Strait-Discovery Passage and 3) Strait of Georgia.

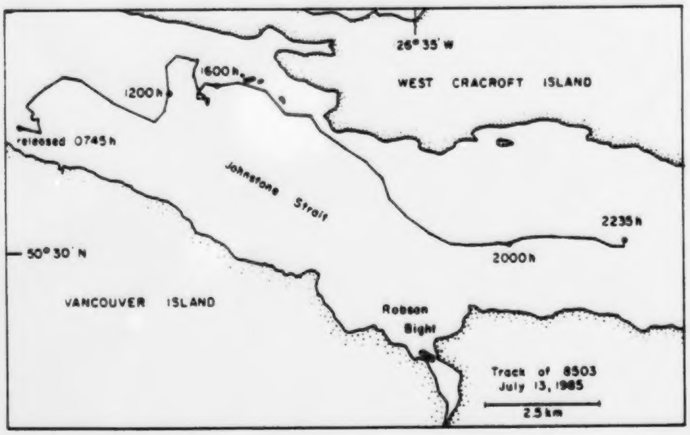

26° 35' W
WEST CRACROFT ISLAND
1600 h
1200 h
released 0745 h
Johnstone Strait
2235 h
2000 h
50° 30' N
VANCOUVER ISLAND
Robson Bight
Track of 8503
July 13, 1985
2.5 km

Fig. 4: Track of 8503 through area of upper Johnstone Strait.

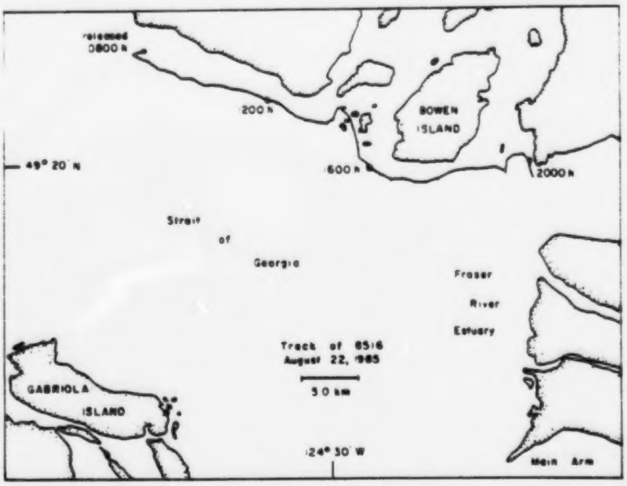

released 0800 h
1200 h
BOWEN ISLAND
49° 20' N
1600 h
2000 h
Strait of Georgia
Fraser River Estuary
Track of 8516
August 22, 1985
5.0 km
GABRIOLA ISLAND
124° 30' W
Main Arm

Fig. 5: Track of 8516 through area of Strait of Georgia.

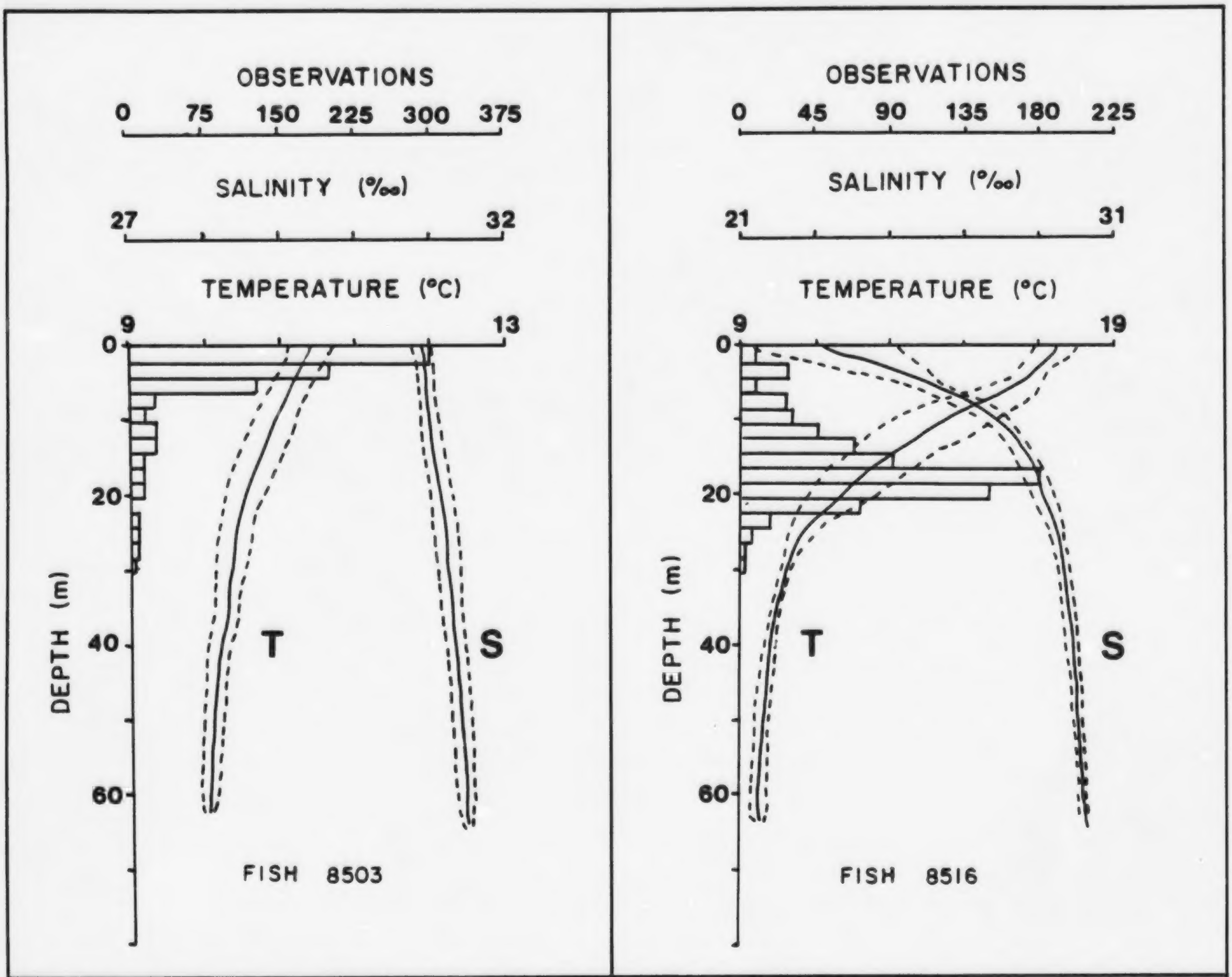
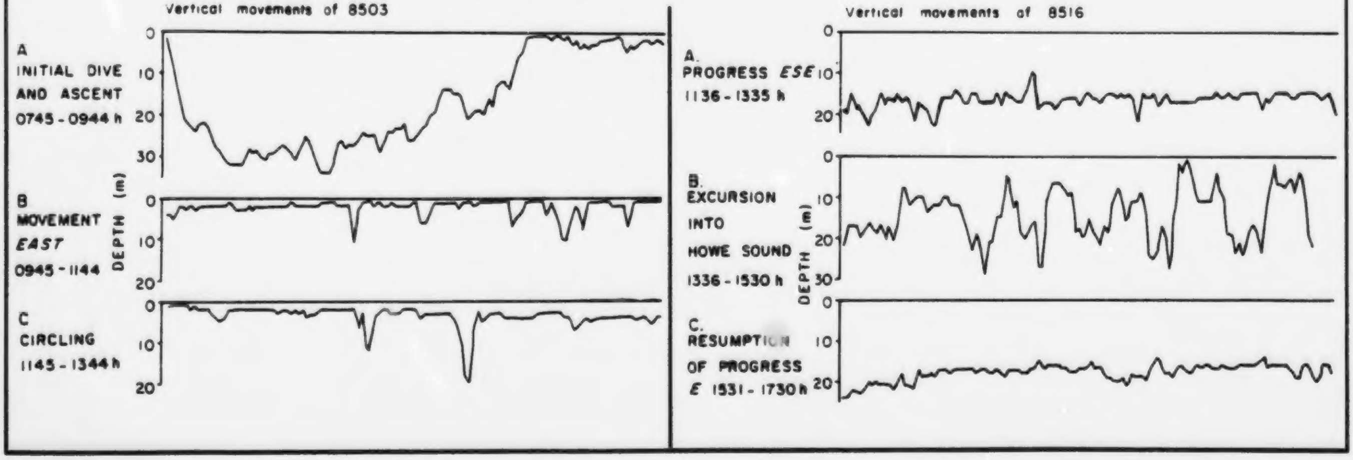


Fig. 6: Depth distributions of fish tracks 8503 and 8516 from two oceanographic regimes. Upper graphs show number of 1min observations at a given depth, and the temperature (T) and salinity (S) observed at those depths. Lower plots illustrate vertical profiles.



Panel Discussion on DFO Opportunities and Issues in Hydroacoustics

The last session of the Workshop was intended to summarize the previous sessions and provide a forum to discuss problems and future directions for hydroacoustics R&D from a DFO perspective. Each Chairman provided a brief synopsis of the main points that arose during the presentation and discussion of individual papers in their session. A lengthly plenary discussion was then held in which participants provided their views on how problems might be tackled and which priority issues should be addressed by DFO in the short and long terms. All comments raised during their portion of the program are categorized into the generic summary presented below. They are presented as identified needs; not necessarily as recommendations from the Workshop since it was recognized that some could not be implemented under current fiscal restraints. The needs are not presented in order of priority.

Team Approach

DFO expertise in hydroacoustics R&D is varied and diverse, and scattered amongst regional research facilities. It includes expertise from areas such as acoustics, engineering, biology, mathematics, oceanography and engineering. It was recognized that many of the complex interdisciplinary problems being addressed through acoustical techniques, if they were to be efficiently and scientifically handled, required some sort of a pooling of departmental talents. Several possibilities were suggested: additional workshops, technological service centres, centres of disciplinary expertise (CODE), centres of excellence, and coordinating committees - regional and/or national. The present workshop had already resulted in new relationships being formed between individuals with different talents; workshop participants are now able to contact these individuals directly to discuss problems and potential solutions. The workshop therefore contributed a valuable first step in identifying departmental expertise that could be applied to specific problems. The concept of "networking" to promote information exchange amonst acoustic experts was seen as an efficient mechanism; again the workshop has significantly contributed to this network. Industry had been consciously left out of the Workshop since it was intended as an internal DFO discussion of ongoing efforts, problems and opportunities. Now that the Workshop has taken place it was recognized that the "network" linkages would have to be expanded to include industrial involvement in DFO acoustics research. The same is true for maintaining contact with university efforts in hydroacoustic research. The possibility of a regular "newsletter" on hydroacoustics research in Canada was suggested.

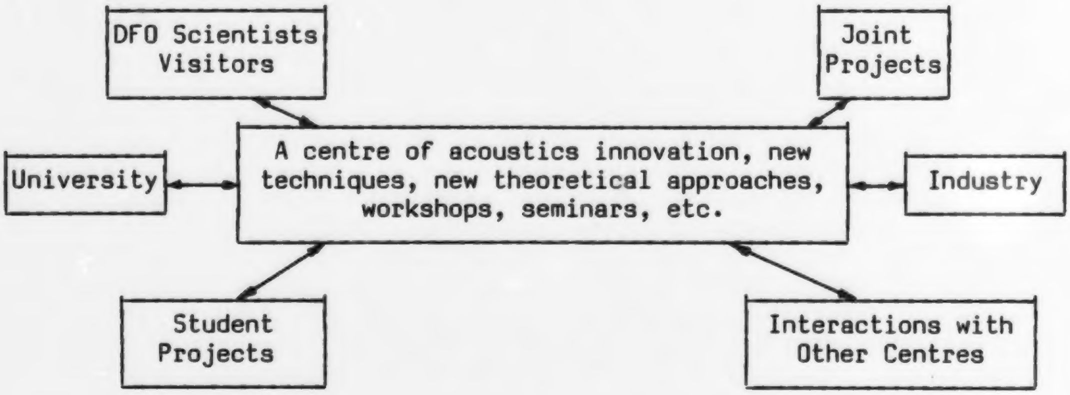
Centres

Two different types of centres of expertise were identified as being needed.

(i) Technology: A critical mass of engineers/technicians/scientists dealing with acoustic-related technologies exist at only a few DFO laboratories (BIO, IOS and to a limited extent NAFC and Bayfield). Other centres (FWI, Nanaimo, MLI) are severely limited in their ability to plan and implement acoustic programs due to their lack of proximity to such technological expertise. This is not to say that such expertise should be pooled; to be drawn upon by all regions needing such support. Rather inter-laboratory cooperative mechanisms need to be fostered that would allow technology poor centres to draw on the expertise and resources of technology rich (relatively) centres.

(ii) Science: Aside from hardware/software considerations noted under the previous section, there was a recognized need to maintain and enhance DFO's leadership in hydroacoustic physics. This leadership primarily resides with Dr. David Farmer at IOS. Dr. Farmer is an acknowledged world expert and is at the cutting edge of acoustic research. Collaboration with the US Office of Naval Research and the university research community has been an important facet of developing the scientific excellence associated with Dr. Farmer's operation. Unfortunately the IOS science program in acoustics is below critical mass, particularly with respect to PYs. Two possibilities were discussed to further develop the existing scientific capability. A CODE, while creating the necessary visibility for acoustics research in the Department and would protect an important research area from ongoing operational demands, would not likely generate the required additional resources for acoustic science. It was suggested, instead, that efforts should be made to set up a Centre of Excellence in hydroacoustics, modelled along the lines currently being encouraged by MOSST, which would be a research partnership amongst industry, universities and DFO.

A model was presented to the Workshop as follows, which conceptualized the symbiotic relationship of such a centre.


DFO Scientists Visitors
Joint Projects
University
A centre of acoustics innovation, new techniques, new theoretical approaches, workshops, seminars, etc.
Industry
Student Projects
Interactions with Other Centres

While it is important to give such a centre sufficient freedom to follow innovative, risky research paths, it should ensure that sufficient linkages are maintained with real-world DFO problems so as to ensure that applied requirements are taken into account.

In any case it was generally agreed that the Centre of Excellence would fulfill a "science" need and would not serve the needs of a technology service need outlined previously, e.g. would not be concerned with equipment calibration, etc.

Calibration

Careful calibration of equipment is needed to understand what is being measured and to facilitate intercomparison of survey and research results. The need for inter-regional standardization of calibration methods was also recognized. The technology support centres mentioned previously could regularize DFO and other agency calibration requirements. The need for "total system" calibration was recognized. An offshore calibration facility on the East Coast, coordinated by NSRF, is a concept that was discussed in the 1970s. The possibility of an acoustic range test facility might be further explored. An inventory of existing calibration capabilities would be useful.

Equipment

(i) Multiple Use: There is a need to ensure efficient use of acoustic instrumentation through their joint use by DFO researchers.

(ii) Development: There is a need to ensure: (i) the priority for developing new technologies for hydroacoustic research, and that (ii) new initiatives in equipment development are well reviewed across the Department before resource commitments are made. Additionally, advances in micro-electronics should be incorporated wherever possible to reduce equipment size and increase speed.

Data Manipulation

Emphasis needs to be placed on enhancing techniques to deal with the processing and analyzing of the large data sets that are emanating from the various acoustic sensors.

Signal Interpretation

Much research needs to be undertaken in the area of analyzing various acoustic signals and interpreting their meaning, including:

- secondary scattering
- doppler signals for fish/species recognition
- marine mammal recognition (possibly through voice pattern recognition)
- conversion of acoustic measurements into specific estimates, such as biomass

Leadership

If successful development is to take place, it was noted that there was need of a champion for a system development; one proactive person needs to be dedicated to look after the entire project proposal and implementation. To accomplish this, HQ Science should strengthen their national role in coordinating the different elements of the program.

Models

In biology there is a need for a good acoustics model that can be used to assess fish stocks where traditional models have proven to be inadequate.

Subventions

In view of the recently expanded resources available to the DFO Science Subventions Program, it was thought opportune to encourage future proposals in the area of hydroacoustics research.

Surveys

More scientific effort is required in designing methodologies for valid fish surveys using acoustic techniques, with proper verification of results.

Funding

It was recognized that much of the acoustic R&D in the Department was being accomplished with "soft money". While it is essential that these resources continue to be secured to carry on further research it must be recognized that the work is being performed for outside clients and as such we often do not have full control of the outputs.

Additionally it was noted that technological advances are proceeding at a faster rate than they can be assimilated through procurement with available DFO resources. Our survey work is often being undertaken with inadequate equipment.

Summary of Recommendations

Much of the foregoing will be taken into account through the normal evolution of DFO acoustic science programs. Additionally, three specific actions will be taken:

(i) The National Science Directors Committee will be briefed on the importance of and opportunities for hydroacoustic research in the Department. This should raise the profile of the subject matter and will further information exchange requirements, and establish a forum for discussing possible joint programs and equipment development and usage possibilities.

(ii) The Science Subventions Program will be investigated as a means of encouraging additional university involvement in hydroacoustics research.

(iii) The possibility of establishing a Centre of Excellence in Hydroacoustics along the lines being conceptualized by MOSST will be investigated through the university community. Resources for such a Centre would have to be provided to a university(s) and not at the expense of ongoing DFO acoustic research efforts.

LIST OF PARTICIPANTS

NAME	ORGANIZATION	TELEPHONE NO.
Peter Barr	P.I.	
Don Belliveau	DFO/BIO	902 - 426-3619
Andrew Bennett	DFO/BIO	902 - 426-2039
Paul Boudreau	DFO/BIO	902 - 426-7564
Udo Buerkle	MFD, St. Andrews	506 - 529-8854
Bob Burke	CHS/BIO	902 - 426-3657
Allen Clay	Femto Electronics Ltd.	902 - 865-8565
Norman Cochrane	BIO	902 - 426-2447
Graham Collins	BIO/BIOMAIL	902 - 426-3698
Ken Cooke	DFO/PBS	604 - 756-7174
Sue Cosens	DFO/FWI	204 - 983-8838
Gerard Costello	CHS/BIO	902 - 426-2432
Rick Crawford	DFO/FWI	204 - 983-5061
Terry Curran	DFO/IOS Eng'g Services/CHS	604 - 356-6583
Lloyd Dickie	DFO/BIO	902 - 426-3248
Don Dinn	DFO/BIO	902 - 426-3700
Ross Douglas	CHS	613 - 995-4413
Jim Elliott	DFO/Scotia-Fundy	902 - 426-8478
David Farmer	DFO/IOS	604 - 356-6591
Brian Fraser	DFO/BIO	902 - 426-3859
Arnold Furlong	Brooke Ocean Tech.	902 - 466-4075
Jim Galloway	IOS	604 - 356-6316
Sean Gomez	Seastar Instr. Ltd.	902 - 464-0939
Fred Guptill	Seastar Instruments Ltd.	902 - 464-0939
Jean-Eudes Haché	DFO/RDG	902 - 426-2581
Patrick Hally	CHS/Quebec	418 - 775-6505
Doug Hay	DFO/PBS	604 - 756-7201
Bill Hinds	IOS/Eng'g Services	604 - 356-6313
Geoff Holland	DFO/Ottawa	613 - 990-0298
Brian Jessop	DFO/ECAF	902 - 426-2158
Robert Kieser	PBS	604 - 756-7039
George Lobb	DFO/MLI	418 - 775-6564
Dave Mackas	DFO1/IOS	604 - 356-6442
Steve MacPhee	DFO/Science	902 - 426-3492
Ken Mann	DFO/BIO	902 - 426-3696
Michel Masson	BIO	902 - 426-3472
Dave McKeown	DFO/BIO	902 - 426-3489
Doug McKone	DFO/Ottawa	613 - 990-0285
Dan Miller	DFO/St. John's, Nfld.	709 - 772-5542
Jim Parks	IOS	604 - 356-6315
Russ Parrott	EMR/GSC/AGC	902 - 426-7059
Simon Prinsenberg	DFO/BIO	902 - 426-3985
Nelson Rice	Brooke Ocean Tech. Ltd.	902 - 466-4075
Bob Ryan	Seimac Limited	902 - 463-9686
Peter Ryan	DFO	604 - 666-3481
Doug Sameoto	DFO/BIO	902 - 426-3272
Yvan Simard	DFO/MLI	418 - 775-6527
Andrzez Stephnowski	Seastar Instr. Ltd.	902 - 464-0939
Chris Stevens	DFO/St. John's	709 - 772-4916
Dick Stoddart	DFO/PCSD	613 - 990-0302